STATE OF MONTANA
NATURAL RESOURCE DAMAGE PROGRAM

AQUATIC RESOURCES
INJURY ASSESSMENT REPORT

UPPER CLARK FORK RIVER BASIN

JUNE 1993

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LIST OF ACRONYMS

AET	Apparent Effects Threshold
ARCO	Atlantic Richfield Company
AWQC	Ambient Water Quality Criteria
CFS	Cubic Feet per Second
CWA	Clean Water Act
DOI	United States Department of the Interior
EP	Ephemeroptera, Plecoptera
EPA	United States Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, Tricoptera
GFAA	Graphite Furnace Atomic Absorption Spectroscopy
ICP	Inductively Coupled Plasma Spectroscopy
IDL	Instrument Detection Limit
IFIM	Instream Flow Incremental Methodology
KTL	Growth Condition Factor
MBMG	Montana Bureau of Mines and Geology
MDFWP	Montana Department of Fish, Wildlife, and Parks
MDHES	Montana Department of Health and Environmental Sciences
MDSL	Montana Department of State Lands
MGD	Million Gallons per Day
MSD	Metro Storm Drain
MTN	Metallothionein
NRDA	Natural Resource Damage Assessment
NRDP	Montana Natural Resource Damage Program
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priorities List
PCP	Pentachlorophenol
PHABSIM	Physical Habitat Simulation
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
RI/FS	Remedial Investigation/Feasibility Study
RPD	Relative Percent Difference
SET	Severe Effects Threshold
TR	Total Recoverable
U.S. EPA	United States Environmental Protection Agency
U.S. FWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant
WUA	Weighted Usable Area

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1.0 SUMMARY AND INTRODUCTION

Aquatic resources of the upper Clark Fork River Basin have been injured as a result of historic and ongoing releases of hazardous substances. The upper Clark Fork River Basin Aquatic Resources Injury Assessment Report describes the results of injury determination and quantification for these aquatic resources. Resources addressed in this report include surface water, stream- and riverbed sediments, benthic macroinvertebrates, and fish. The geographic scope of the injury assessment includes Silver Bow Creek (from below the Colorado Tailings in Butte to the Warm Springs Ponds) and the Clark Fork River (from its headwaters just below the Warm Springs Ponds to the Milltown Reservoir)[1] (Figure 1-1).

The Aquatic Resources Injury Assessment Report describes injuries to surface water, benthic macroinvertebrates, and fish that have resulted from historic and ongoing releases of the hazardous substances arsenic, cadmium, copper, lead, and zinc from mining and mineral-processing operations in Butte and Anaconda. The following information on aquatic resources is presented in the various chapters of the Report:

<u>Surface Water</u>

- Surface water resources have been injured throughout the length of Silver Bow Creek and the Clark Fork River.
- Surface water resources are exposed to hazardous substances via upstream surface water, surface run-off, bed, bank, and floodplain sediments, and groundwater.
- Surface water serves as a pathway of hazardous substances to sediments and fish.

<u>Sediments</u>

- Stream- and riverbed sediments have been contaminated with hazardous substances throughout the length of Silver Bow Creek and the Clark Fork River. These contaminated sediments act as a critical exposure pathway to injured surface water and aquatic biota, particularly benthic macroinvertebrates.

[1] Hereafter, unless otherwise noted, the designations "Silver Bow Creek" and the "Clark Fork River" are used to refer to these geographic definitions.

Benthic Macroinvertebrates

- Aquatic insects ("benthic macroinvertebrates") have been exposed and injured throughout the length of Silver Bow Creek.

  Benthic macroinvertebrates have been exposed to hazardous substances throughout the length of the Clark Fork River, predominantly through sediment exposure pathways. These exposed and/or injured invertebrates act as a critical exposure pathway to injured fish.

Fish

- Fish have been injured throughout the length of Silver Bow Creek and the Clark Fork River. In Silver Bow Creek, fish have been eliminated entirely. In the Clark Fork River, trout populations have been reduced below baseline conditions by, on average, a factor of more than three. Rainbow trout largely have been eliminated from the Clark Fork River upstream of Rock Creek.

- Restoration of fish populations to baseline conditions requires restoration of surface water, sediments, and benthic macroinvertebrates; all serve as exposure pathways to injured fish.

Table 1-1 provides a summary of natural resource injuries and exposure pathways.

Table 1-1
Injury and Pathway Summary for Aquatic Resources

Natural Resource	Geographic Location	Injuries	Pathways to Injured Resource
Surface water	▸ Silver Bow Creek ▸ Clark Fork River	▸ Concentrations of hazardous substances exceed federal water quality criteria ▸ Concentrations of hazardous substances in surface water cause injury to fish	▸ Surface water ▸ Sediments (bed, bank, floodplain) ▸ Groundwater
Fish	▸ Silver Bow Creek ▸ Clark Fork River	▸ Death ▸ Behavioral avoidance ▸ Physical deformation ▸ Reduced growth	▸ Surface water ▸ Food chain (benthic macroinvertebrates)
Benthic macroinvertebrates	▸ Silver Bow Creek[1]	▸ Death ▸ Reduced biodiversity	▸ Sediments

[1] The benthic macroinvertebrates of the Clark Fork River also serve as a pathway of hazardous substances to fish.

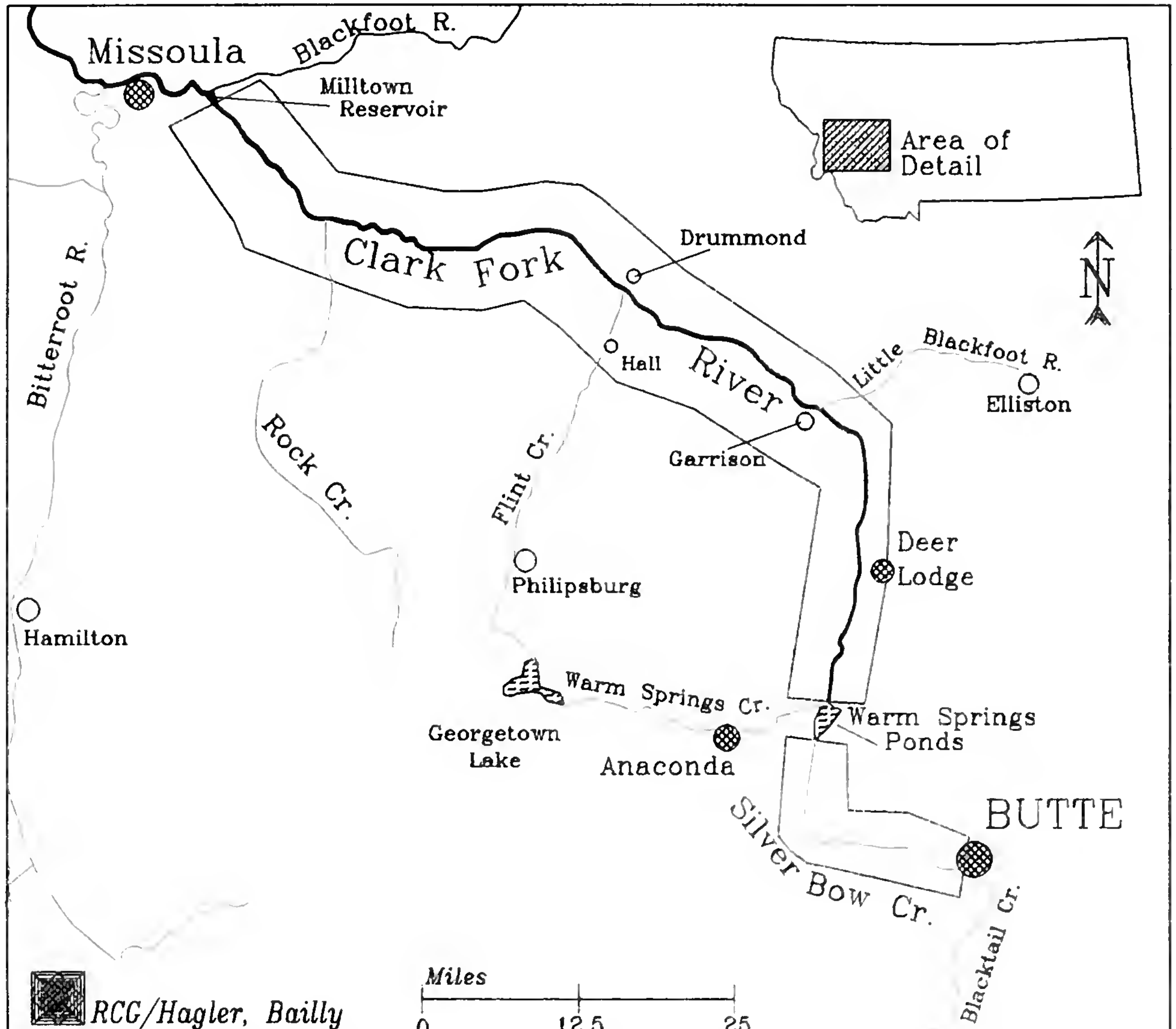

Figure 1-1. Geographic Scope of Injury to Aquatic Resources: Silver Bow Creek and the Clark Fork River.

1.1 INJURY ASSESSMENT OVERVIEW

The U.S. Department of the Interior (DOI) has promulgated regulations for the performance of natural resource damage assessments [43 CFR Part 11]. This assessment was performed in accordance with these regulations.

The term "injury" is defined as a

> "measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a release of a hazardous substance, or exposure to a product of reactions resulting from the release of a hazardous substance." [43 CFR § 11.14 (v)].

The assessment of injury to aquatic resources of the Clark Fork River Basin included the following three phases:

1. Injury Definition. In the injury definition phase, those injuries that were found to meet the definitions of injury in 43 CFR § 11.62 were evaluated.

2. Pathway Determination. In the pathway determination phase, exposure pathways of hazardous substances to injured natural resources were identified [43 CFR § 11.63]. The Department of the Interior notes that pathway determination may be is accomplished by the: "demonstration of sufficient concentrations in the pathway for it to have carried the substance to the injured resources." [51 FR 27684]. In this assessment, "sufficient concentrations" of hazardous substances in pathway resources have been demonstrated in surface water, groundwater, sediments, benthic macroinvertebrates, and forage fish.

These first two steps constituted the "injury determination" phase of the assessment. The final phase consisted of "injury quantification":

3. Injury Quantification. The effects of the releases of hazardous substances were quantified in terms of changes from "baseline conditions" [43 CFR § 11.70 (a)]. Specific steps in the quantification phase included measuring the extent of the injury relative to baseline conditions and determining the recoverability of the resource [43 CFR § 11.71 (b)].

Baseline conditions are the conditions that "would have existed at the assessment area had the...release of hazardous substance...not occurred" [43 CFR § 11.14 (e)] and are the conditions to which injured natural resources should be restored [43 CFR § 11.14 (ll)]. Baseline conditions should take into account both natural processes and human activities, and should include the normal range of physical, chemical, or biological conditions for

the assessment area or injured resource. [43 CFR § 11.72 (b)]. In addition, baseline data collection "shall be restricted to those data necessary for a reasonable cost assessment." [43 CFR § 11.72 (b)(4)]. Where historical baseline data are not available, "baseline data should be collected from control areas." [43 CFR § 11.72 (d)]. "Control area" is defined as "an area or resource unaffected by the discharge...or release of the hazardous substance under investigation. A control area or resource is selected for its comparability to the assessment area or resource and may be used for establishing the baseline condition and for comparison to injured resources" [43 CFR § 11.14 (i)]. Control area selection is based on criteria set forth at 43 CFR § 11.72 (d)(1-7):

- One or more control areas shall be selected based upon their similarity to the assessment area and lack of exposure to the...release.

- Where the...release occurs in a medium flowing in a single direction, such as a river or stream, at least one control area upstream or upcurrent of the assessment area shall be included, unless local conditions indicate such an area is inapplicable as a control area.

- The comparability of each control area to the assessment area shall be demonstrated, to the extent technically feasible, as that phrase is used in this part.

- Data shall be collected from the control area over a period sufficient to estimate normal variability in the characteristics being measured and should represent at least one full cycle normally expected in that resource.

- Methods used to collect data at the control area shall be comparable to those used at the assessment area, and shall be subject to the quality assurance provisions of the Assessment Plan.

- Data collected at the control area should be compared to values reported in the scientific or management literature for similar resources to demonstrate that the data represent a normal range of conditions.

- A control area may be used for determining the baseline for more than one kind of resource, if sampling and data collection for each resource do not interfere with sampling and data collection for the other resources.

Distinct control areas were identified for the assessment of injury to surface water, sediments, benthic macroinvertebrates, and fisheries. These control areas are described in greater detail in the individual injury chapters and accompanying appendices.

<u>Source, Pathway, Exposure</u>

The aquatic resources of Silver Bow Creek and the Clark Fork River that have been exposed to and/or injured by releases of hazardous substances include surface water and sediments, benthic macroinvertebrates, and fish. These natural resources also serve as pathways for contaminant movement within the aquatic ecosystem (Figure 1-2). For example, when hazardous substances are released from sources to surface water, they can accumulate in bed sediments. Hazardous substances in bed sediments, in turn, can expose surface water through chemical desorption reactions. Aquatic macroinvertebrates are exposed to hazardous substances from fine-grained bed sediments. Fish are exposed to hazardous substances through direct contact with contaminated surface water, and through consumption of these contaminated benthic macroinvertebrates.

The assessment of injury to aquatic resources included the following determination of source-pathway-exposure-injury relationships:

(1) Hazardous substances are found in significantly elevated concentrations (relative to baseline conditions) in the "source" and are known to be released from that source to a pathway resource.

(2) Hazardous substances are found in elevated concentrations in the pathway resources.

(3) Natural resources are exposed to the pathway resource and, hence, to the hazardous substances in the pathway.

(4) The exposed natural resources have been injured by the hazardous substances or their by-products.

Figures 1-3 and 1-4 present simplified examples of this relationship for aquatic resources. The two figures show, for Silver Bow Creek and the Clark Fork River, respectively, the ratios of the hazardous substances cadmium, copper, and zinc relative to baseline conditions in surface water, sediments, and benthic macroinvertebrates.

1.2 AQUATIC RESOURCE INJURY REPORT ORGANIZATION AND SUMMARY OF FINDINGS

As described previously, aquatic resources — including surface water, bed sediments, benthic macroinvertebrates, and fisheries have been exposed and injured by hazardous substances in Silver Bow Creek and the Clark Fork River. These injuries to natural resources have resulted from historic and ongoing releases of the hazardous substances arsenic, cadmium, copper, lead and zinc, as well as compounds of these substances.

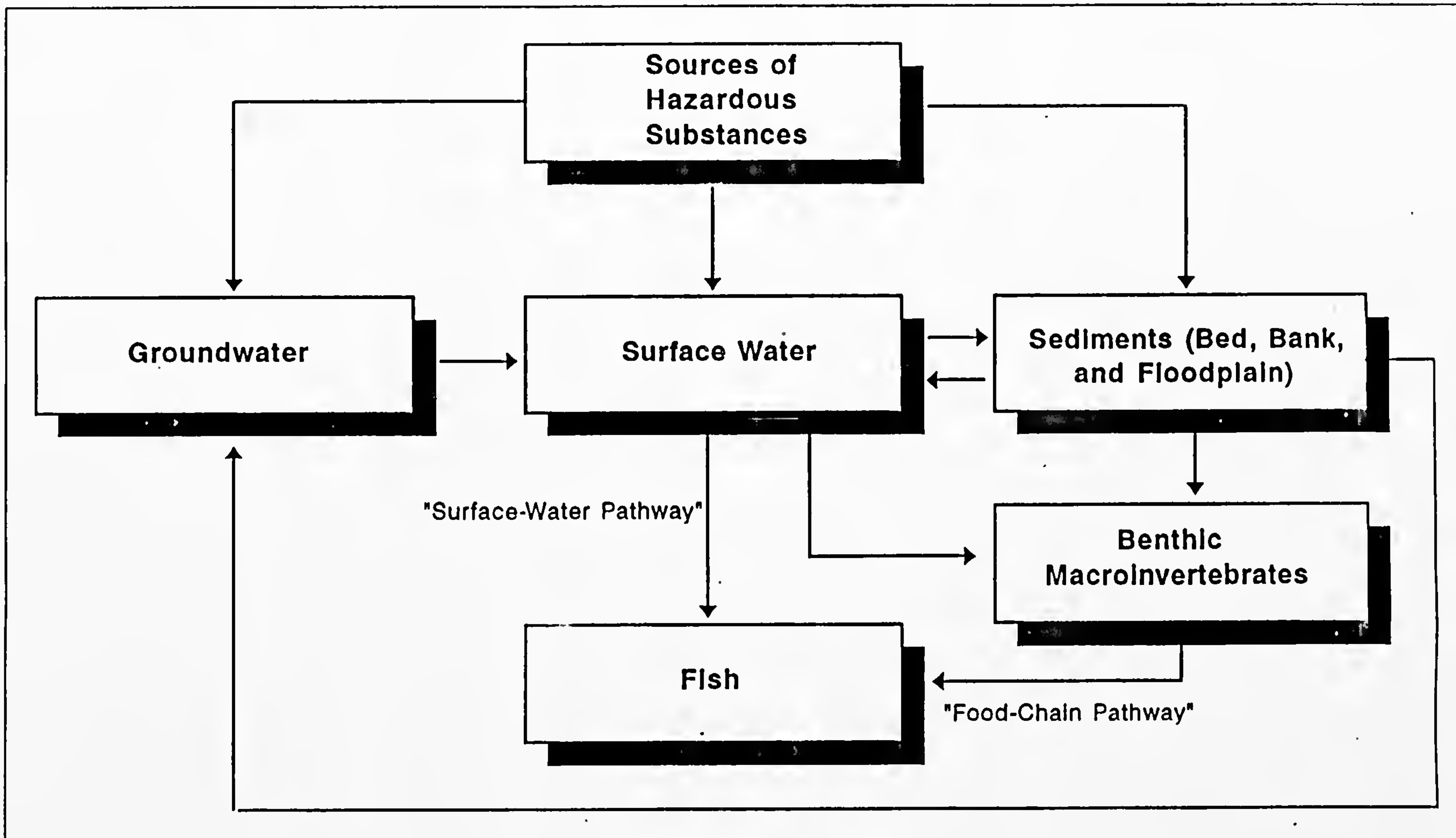

Figure 1-2. Relationships of Aquatic Resources Within the Clark Fork River.

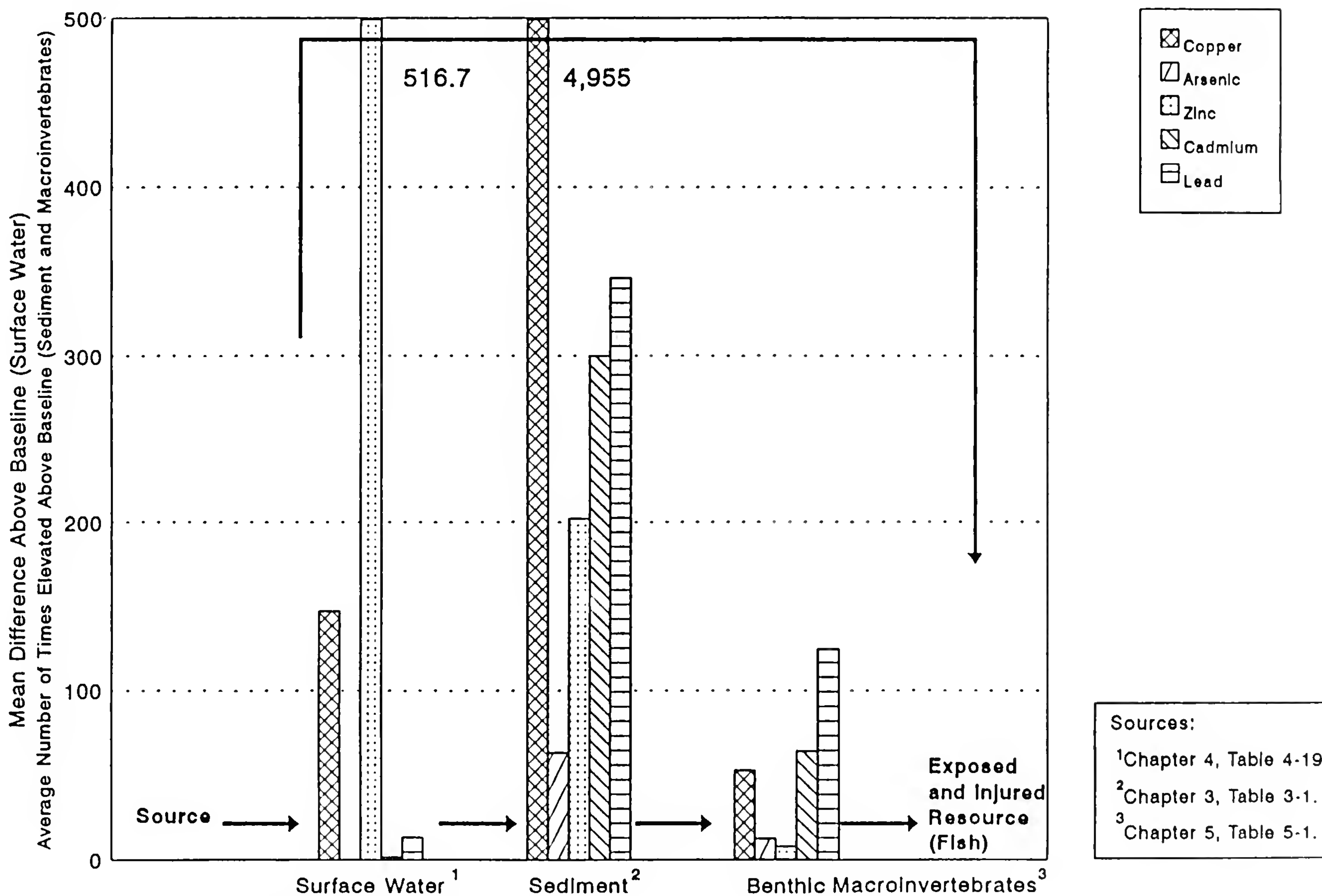

Figure 1-3. Simplified Source-Pathway-Exposure Relationship, Silver Bow Creek.

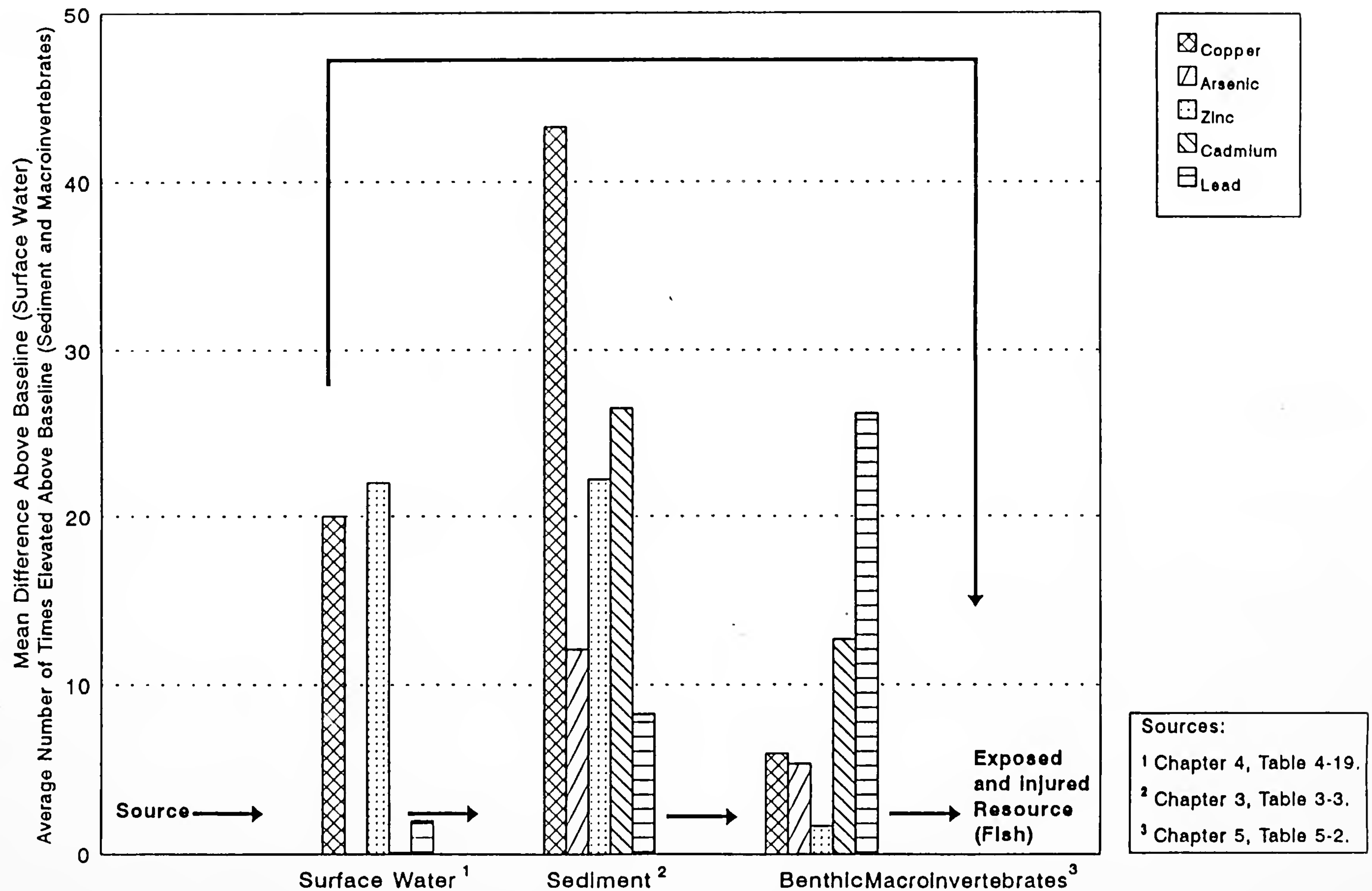

Figure 1-4. Simplified Source - Pathway - Exposure Relationship, the Clark Fork River.

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This aquatic resources injury report is organized as follows: **Chapter two** describes sources of hazardous substances to the aquatic environment. These sources of hazardous substances have been categorized extensively in Remedial Investigation/Feasibility (RI/FS) studies performed as part of Superfund activities at the four National Priorities List (NPL) sites in the Clark Fork River Basin, and are summarized in Chapter two.

Principal sources of hazardous substances released into the Silver Bow Creek/Clark Fork River aquatic environment include:

- Historic discharges from mines and mills located in the Butte and Anaconda areas
- Mine dumps, mill dumps, mining/smelting facilities, fill areas, and associated contaminated soils
- The Parrot Tailings impoundment and dispersed tailings in the Butte area
- The Butte Reduction Works Tailings impoundment
- The Colorado Tailings impoundment and dispersed tailings
- Fluvially deposited stream- and riverside tailings devoid of vegetation covering at least 1,500 acres along Silver Bow Creek and the Clark Fork River, as well as at least an additional 5,000 acres of contaminated floodplain soils and sediments
- Contaminated floodplain soils
- The Montana Pole and Treating site
- The Rocker Timber Framing and Treating site
- The settling ponds at Warm Springs ("Warm Springs Ponds")
- The Opportunity Ponds
- The Anaconda Smelter and proximate contaminated soils.

Chapter three presents information and data on concentrations of hazardous substances in bed sediments. These data demonstrate that sediments act as a critical exposure pathway from upstream sources in the Butte area to surface water and biota of Silver Bow Creek and the Clark Fork River.

Chapter three, together with the Sediments Report prepared as part of this Assessment (Essig and Moore, 1992) demonstrates that:

- Concentrations of hazardous substances in bed sediments are significantly elevated above baseline conditions in Silver Bow Creek and the Clark Fork River.

- Bed sediment analysis identifies upstream sources in Butte and Anaconda to be the dominant and principal sources of hazardous substances to the Clark Fork River aquatic system.

- Other than Silver Bow Creek, tributaries to the Clark Fork River are <u>not</u> major sources of hazardous substances.

- Concentrations of hazardous substances in bed sediments are sufficient to cause injury to aquatic benthic macroinvertebrates in Silver Bow Creek.

- Hazardous substances in bed sediments in the Clark Fork River are biologically available, and are bioaccumulated by benthic macroinvertebrates.

- Bed sediments are a critical exposure pathway to surface water, benthic macroinvertebrates, and, via food chain pathways, fish. Failure to restore bed sediments will therefore preclude restoration of these injured aquatic resources.

Chapter four describes injuries to surface water resources. This chapter shows that:

- Surface water resources of Silver Bow Creek and the Clark Fork River exceed ambient water quality criteria established under the Clean Water Act and hence have been injured.

- Surface water concentrations of hazardous substances in Silver Bow Creek and the Clark Fork River are significantly greater than baseline conditions.

- Surface water concentrations of hazardous substances in Silver Bow Creek and the Clark Fork River are sufficient to cause injury to fishery resources.

Chapter five presents information and data specific to aquatic benthic macro-invertebrates. This chapter focuses on the uptake and accumulation of hazardous substances by macroinvertebrates resulting in injury to fish. In addition, Chapter five demonstrates that invertebrates themselves have been injured in Silver Bow Creek. As described in this chapter, together with the Sediments Report (Essig and Moore, 1992):

- Hazardous substances in bed sediments of Silver Bow Creek and the Clark Fork River are bioavailable to benthic macroinvertebrates.

- Bioaccumulation of hazardous substances from Silver Bow Creek and Clark Fork River sediments by benthic macroinvertebrates has been documented in both field studies and controlled laboratory studies.

- Benthic macroinvertebrates in Silver Bow Creek have been injured by exposure to hazardous substances. Contaminated sediments from Silver Bow Creek were found to cause mortality to benthic macroinvertebrates. This mortality has caused the number of macroinvertebrate taxa to be reduced relative to baseline conditions. A similar pattern of reduced macroinvertebrate taxa has been observed in the Clark Fork River; this may indicate that macroinvertebrates are injured in the Clark Fork River also.

- Sediment concentrations of arsenic, copper, lead, and zinc in Silver Bow Creek are well above sediment threshold concentrations (developed by the National Oceanic and Atmospheric Administration and the Ontario Ministry of the Environment) that are expected to adversely affect benthic communities.

Chapter six, together with the Fisheries Toxicology Reports (Appendices B-F of this report) and the Fisheries Population Report (Appendix G of this report), describe the determination and quantification of injury to fish populations in Silver Bow Creek and the Clark Fork River.

The results of **injury determination** for fishery resources include the following conclusions:

- Injuries to fish that have resulted from exposure to hazardous substances in surface water and in food-chains include death, behavioral avoidance, reduced growth, and physical deformations.

- Death has been confirmed by fishkills, *in situ* bioassays, and controlled laboratory studies.

- Laboratory studies demonstrated that exposure to acute pulses of elevated hazardous substances similar to those documented in the Clark Fork River causes significant trout mortality.

- Laboratory toxicity studies demonstrated that rainbow trout are more sensitive than brown trout to acute metals pulses.

- Standard laboratory toxicity studies (LC50, LT50 determinations) demonstrated that exposure to copper, cadmium, lead, and zinc at concentrations documented in the Clark Fork River causes significant trout mortality.

- Laboratory studies demonstrated that both brown and rainbow trout avoid hazardous substances at concentrations regularly documented in the Clark Fork River. These studies also determined that rainbow trout are more sensitive than brown trout to avoiding hazardous substances.

- Behavioral avoidance likely limits the immigration of fish ("recruits") from tributaries into the Clark Fork River, as well as causing out-migration into tributaries.

- Laboratory studies documented that food-chain pathways injure trout. Fish fed diets of contaminated Clark Fork River invertebrates demonstrated increased mortality and decreased growth.

- Reduced growth, an indicator of compromised survivability in the field, was documented in controlled laboratory studies. The weight of evidence suggests that growth has been reduced in free-ranging fish collected from the Clark Fork River.

- A consistent pattern of metal accumulation in tissues, degeneration of digestive cells (likely leading to reduced growth), cellular damage, and synthesis of enzymes required to detoxify/excrete metals (production of which entails a metabolic cost which may reduce growth and long-term survivability) was observed in both laboratory-exposed and free-ranging organisms from the Clark Fork River.

- Overall, the results of the fish health studies, including both laboratory and field assessments, present a consistent pattern of (1) exposure to hazardous substances, (2) cell damage (including digestive system degeneration, lipid peroxidation, and liver abnormalities), and (3) reduced growth. These health impairments likely contribute to reduced survivability of trout in the Clark Fork River.

The above conclusions all indicate the presence of multiple and pervasive injuries to resident fish of Silver Bow Creek and the Clark Fork River.

The results of **injury quantification** for fishery resources of Silver Bow Creek and the Clark Fork River demonstrate that the injuries that have resulted from exposures to hazardous substances have resulted in the total elimination of fish from Silver Bow

Creek, substantial reductions in the number of trout present in the Clark Fork River, and reductions in the diversity of trout species in Silver Bow Creek and the Clark Fork River.

Specifically, the results of injury quantification studies supported the following conclusions:

- Fish have been entirely eliminated from Silver Bow Creek despite the availability of habitat. By contrast, Silver Bow Creek baseline conditions supported, on average, over 250 trout per hectare, including rainbow trout, brown trout, and brook trout.

- Overall, trout density in the Clark Fork River is less than one-fourth of baseline. When normalized for habitat, trout density in the Clark Fork River is less than one-third of baseline.

- Both brown trout and rainbow trout were significantly more abundant at control sites. Brown trout numbers and biomass were both roughly one-fourth of baseline. Rainbow trout numbers and biomass were roughly one-fifth of baseline.

- Rainbow trout largely are absent from the Clark Fork River upstream of its confluence with Rock Creek. This observation is consistent with the sensitivity of rainbow trout to acute pulse toxicity and to behavioral avoidance, as shown in injury determination sections.

- The amount of habitat and streamflow were similar between Silver Bow Creek, the Clark Fork River and matching control sites. This supports the conclusion that the observed reductions in trout populations in Silver Bow Creek and the Clark Fork River relative to baseline conditions are not caused by either habitat or flow differences.

Overall, the conclusion of this aquatic resource injury report is that releases of the hazardous substances arsenic, cadmium, copper, lead, and zinc (and their compounds) from mining and mineral processing in Butte and Anaconda, have injured surface water, benthic macroinvertebrates, and fish. In addition, the releases have exposed sediments — a critical pathway resource — to elevated concentrations of hazardous substances throughout Silver Bow Creek and the Clark Fork River. Without restoration, the natural recovery time of these resources is predicted to be hundreds, if not thousands of years.

1.3 REFERENCE

Essig, D.A. and J.N. Moore. 1992. Clark Fork Damage Assessment: Bed Sediment Sampling and Chemical Analysis Report. Report to the State of Montana, Natural Resource Damage Program.

2.0 SOURCES OF HAZARDOUS SUBSTANCES TO AQUATIC RESOURCES OF SILVER BOW CREEK AND THE CLARK FORK RIVER

2.1 INTRODUCTION

This chapter describes sources of hazardous substances released to Silver Bow Creek and the Clark Fork River. In addition, periods of hazardous substance releases as well as the volumes of waste material contained within sources or source areas are identified. Summary information on current and ongoing releases is contained in pathway subsections of this chapter. Finally, data are provided on concentrations of hazardous substances measured in sources and source areas. This chapter is not intended to describe all sources and releases of hazardous substances; that information is contained in many reports prepared as part of the RI/FS. Rather, this chapter summarizes information regarding general source categories.

General source categories of hazardous substances to Silver Bow Creek and the Clark Fork River include historic discharges of mine and mill wastes, waste rock dumps, exposed and buried tailings impoundments, dispersed tailings, mine, mill, smelter and wood treating facilities, and contaminated fill materials. Many sources in the Butte area were characterized during the Silver Bow Creek Remedial Investigation/Feasibility Study (SBC RI/FS). The data and terminology used in various reports (MultiTech, 1987a; CH_2M Hill and Chen-Northern, 1990) to characterize these sources (particularly tailings impoundments, dispersed tailings, and associated contaminated materials) largely have been used in this chapter. Material types evaluated during the SBC RI/FS included tailings, mixed tailings and alluvium, fill material (e.g., alluvium, sand/gravel/slag, demolition and landfill debris, and waste rock), and underlying materials (peat, silts, sands, gravels) that have been exposed to hazardous substances via pathways. These underlying materials now serve as secondary sources of hazardous substances. Elevated concentrations of arsenic, cadmium, copper, lead, and zinc were measured in most material types, including the exposed underlying materials.

This chapter is organized as follows: Section 2.2 describes sources of hazardous substances released to Silver Bow Creek, and Section 2.3 describes sources of hazardous substances released to the Clark Fork River.

2.2 SOURCES OF HAZARDOUS SUBSTANCES TO SILVER BOW CREEK

The principal sources of hazardous substances to Silver Bow Creek (Figure 2-1) are:

1. Historic discharges from mines and mills.

2. Mine dumps, mill dumps, mining/smelting facilities sites, fill areas, and associated contaminated soils.

3. The Parrot Tailings impoundment and dispersed tailings in the Metro Storm Drain area.

4. The Butte Reduction Works Tailings impoundment and dispersed tailings in the Butte Reduction Works area.

5. The Colorado Tailings impoundment and dispersed tailings.

6. Approximately 1,000 acres of fluvially deposited streamside tailings devoid of vegetation along Silver Bow Creek.

7. The Montana Pole and Treating site.

8. The Rocker Timber Framing and Treating site.

These source categories are described in Sections 2.2.1 through 2.2.8. Section 2.2.9 summarizes information concerning the solubility of hazardous substances in the various waste categories. Section 2.2.10 summarizes information on pathways from sources to Silver Bow Creek.

2.2.1 Historic Discharges from Mines and Mills

Wastes containing elevated concentrations of hazardous substances have been discharged directly to Silver Bow Creek and its tributaries for over 100 years since the onset of large-scale copper mining and mineral processing in Butte in approximately 1882. Andrews (1987) estimated that over 110,000,000 tons of metals-contaminated mine and smelter waste were released directly into Silver Bow Creek over the period 1875 to 1959.

Between 1879 and 1885, at least six large smelters were built along Silver Bow Creek from Meaderville to Williamsburg. These operated more or less continuously from 1882 until about 1900 (Smith, 1953). From old photographs and maps of the area, MultiTech (1987b) concluded that tailings were deposited "out the back door" of the smelters and into the channel of Silver Bow Creek. Tailings from the Timber Butte Mill, Butte and Superior, and East Butte concentrators were sluiced to tributaries of Silver Bow Creek until at least 1918 (Flynn, 1937, as cited in MultiTech, 1987b). MultiTech (1987b) calculated that as much as 6,600,000 cubic yards of tailings weighing 8,900,000 tons were produced by smelters in the Butte area from 1880 to 1930.

Early records and maps indicate that dams were built on the creek to contain tailings. An early map of the Butte and upper Silver Bow Creek area (Walcott, 1897) shows tailings dumps from the Colorado Smelter and Parrot Smelter encroaching on the Silver Bow Creek floodplain. A map made in 1904 (F.C. Noble - probable author) shows waste

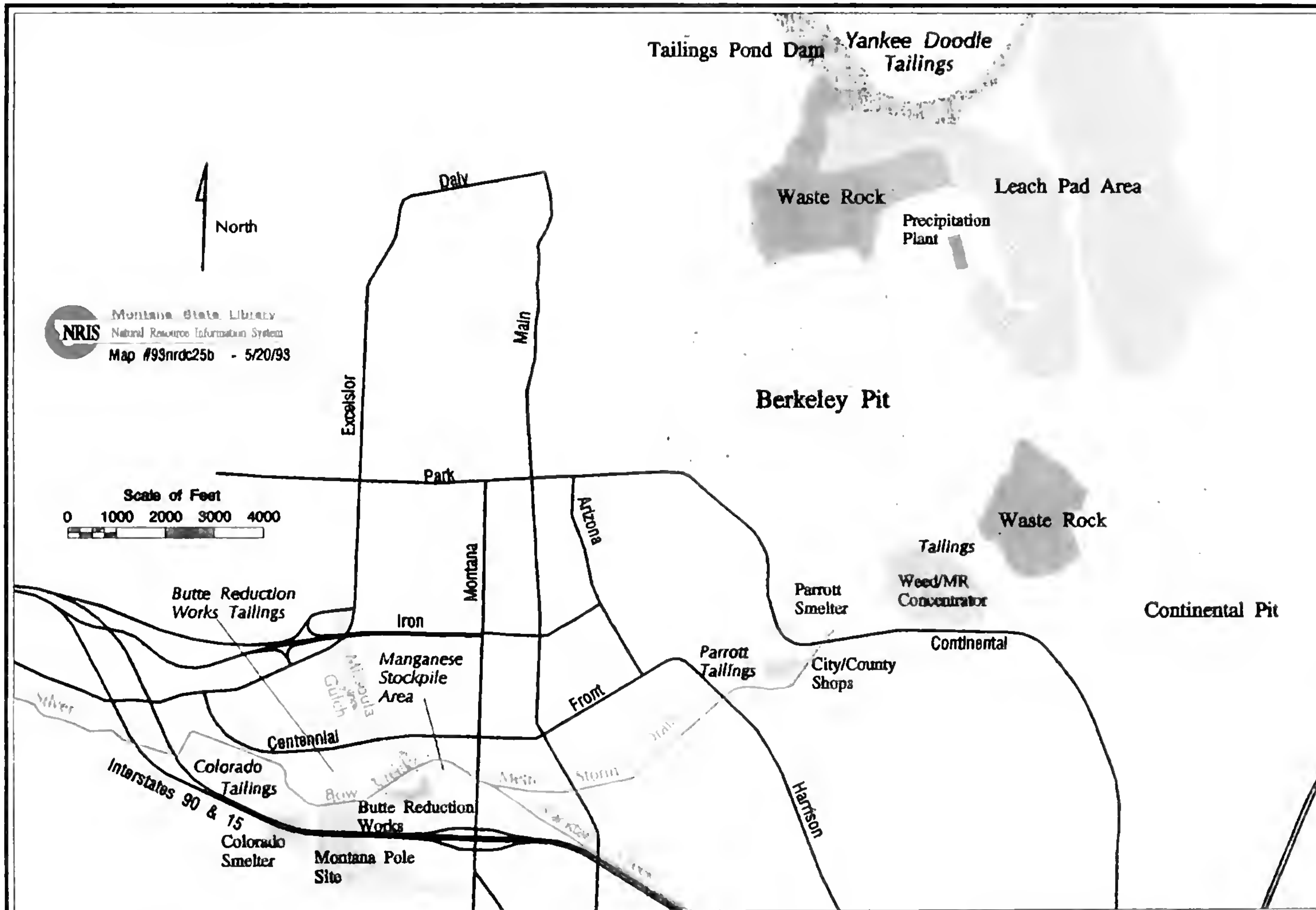

Figure 2-1. Source Areas, Silver Bow Creek.

deposits along the "Deer Lodge River" (Silver Bow Creek) near its confluence with Warm Springs Creek. A 1911 revision of this map by Noble indicates that wastes that had been released to Silver Bow Creek were transported and re-deposited downstream by high flows in 1908 and 1910.

Releases of contaminated minewater to Silver Bow Creek began in about 1882 (MultiTech, 1987b). In 1912, between 4,000 and 5,000 gallons per minute were pumped continuously from all mines in the Butte area (Meinzer, 1914). Most of this water was discharged to Silver Bow Creek (MultiTech, 1987b). Between 1901 and 1955, copper was precipitated from minewater before being discharged to Silver Bow Creek (MultiTech, 1987b). Between 1955 and 1972, minewater was used to leach low-grade ore from Anaconda Company's Berkeley Pit and, after copper precipitation, was discharged to Silver Bow Creek (MultiTech, 1987b; Spindler, 1976).

In 1964, the Weed Concentrator was constructed to concentrate and recover copper from the Anaconda Company's underground mines and the Berkeley Pit. Large amounts of wastewater generated during the concentration and recovery process were discharged to the Metro Storm Drain (MSD), which flows into Silver Bow Creek. In 1972, discharges were derived from tailings pond overflow (6 million gallons per day, or MGD), precipitation plant spent leach solution (6 MGD), excess process water (7 MGD) and overflows from the spills pond (Spindler, 1976). Improvements in water use and recycling in 1973 decreased the volume of discharged wastewater to approximately 12 MGD (6 MGD of process water overflow and 6 MGD of tailings pond overflow). Before closing in 1983, the Weed Concentrator discharged approximately 10 cfs (6.5 MGD) of wastewater containing hazardous substances into the Metro Storm Drain (MultiTech, 1987b, as cited in CDM, 1990).

Discharges of wastewater from the Weed Concentrator contained extremely elevated concentrations of hazardous substances. For example, Spindler (1976) calculated that copper and zinc concentrations in the discharges averaged 70 mg/l and 248 mg/l, respectively, during a 12 month period in 1971 and 1972. Spindler (1976) also summarized metals concentrations in the combined Weed Concentrator discharges from samples collected from the MSD one-quarter mile below the Butte Operations. These concentrations are summarized in Table 2-1 for portions of the years 1971, 1972, 1973, and 1975.

James (1980) reviewed existing water quality data for Silver Bow Creek, flow data from the Weed Concentrator discharge monitoring reports and contemporaneous studies (Peckham, 1979; Beuerman and Gleason, 1978). He calculated that the Weed Concentrator contributed approximately 7.2% of the copper and 2.4% of the zinc measured in Silver Bow Creek at Gregson.

In summary, historic discharges from mines and mills in the Butte area are sources of hazardous substances to Silver Bow Creek:

Table 2-1
Concentrations of Hazardous Substances in the Weed Concentrator Discharges
(concentrations in μg/l)[1]

Sampling Location and Date	Arsenic		Cadmium		Copper		Lead		Zinc	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Process water overflow to Metro Storm Drain[2]										
November 1972	NC	70	<50	<50	NC	2450	<100	100	NC	940
February 1973	NC	361	<50	<50	NC	19,000	NC	260	NC	2800
March 1973	128	128	<50	<50	NC	3000	110	150	NC	2650
April 1973	1	1	<50	<50	NC	1100	<50	<100	NC	260
May 1973	<10	10	<50	<50	NC	600	<100	150	NC	600
June 1973	<10	10	<50	<50	450	950	<100	<100	170	1500
July 1973	<10	10	<50	<50	350	750	<10	<10	120	300
August 1973	NM	NM	NM	NM	NC	2900	NM	NM	NC	550
December 1973	NM	NM	NM	NM	NC	120	NM	NM	NC	220
January 1974	NM	NM	4	4	120	430	<100	<100	50	70
February 1974	40	40	20	20	950	3000	25	25	280	1100
March 1974	90	220	<10	<10	380	950	<50	<50	<120	580
April 1974	130	370	<10	<10	380	2200	<60	90	<100	250
May 1974	116	195	8	10	350	1600	57	70	90	530
July 1974	2	4	5	8	60	210	7	10	30	120
Tailings pond overflow to MSD[2]										
December 1973	2	3	<50	<50	NC	490	<100	<100	NC	980
January 1974	12	12	32	33	170	980	<100	<100	720	2900
February 1974	1	1	40	40	170	400	60	60	640	300
March 1974	43	164	15	30	210	1,000	<50	60	1680	4500
April 1974	NM	NM	NM	NM	90	110	NM	NM	310	460
May 1974	28	95	11	12	45	60	35	75	120	280
July 1974	1	2	13	22	90	280	53	70	460	1700
MSD 1/4 mile below Butte Operations[3]										
Oct 1971 - Sept 1972	NC	NC	NC	NC	70,000	285,000	NC	NC	248,000	1,250,000
Oct 1972 - Sept 1973	NC	NC	NC	NC	1,440	22,400	NC	NC	2070	26,000
1975	NC	NC	NC	NC	100	240	NC	NC	170	350

1 NC = data not calculated. NM = no analyses made.
2 Anaconda Company, Butte Operations, Wastewater Monitoring Results Reports to Montana Department of Health and Environmental Sciences.
3 Spindler, 1976.

- Mine and mill wastes containing elevated concentrations of hazardous substances were discharged, released, or deposited directly in Silver Bow Creek and its tributaries (MultiTech, 1987b).

- Early maps of Butte and Silver Bow Creek (e.g., Walcott, 1897; Noble, 1911) show tailings or other waste deposits located in the Silver Bow Creek drainage adjacent to or downstream from mills and smelters along Silver Bow Creek.

- Discharge monitoring reports from the Weed Concentrator document elevated concentrations of hazardous substances in wastewaters discharged to Silver Bow Creek.

2.2.2 Mine Dumps, Mill Dumps, Mining/Smelting Facilities, Fill Areas, and Associated Contaminated Soils

A number of existing sources of hazardous substances have been identified in the Butte area, including mine dumps, tailings dumps, road fills, mine and mill sites, and associated contaminated soils and sediments. Hydrometrics (1983) identified over 100 inactive mines and associated waste dumps, containing some 10,000,000 cubic yards and 20,000,000 tons of material in a 12 square mile area within and north and west of Butte. Numerous mill sites, unreclaimed and reclaimed waste rock dumps, and drainages were characterized in the Butte Soils Screening Study (CDM, 1988). Table 2-2 provides hazardous substance concentrations at these source areas in Butte.

Many of these sites are located in surface and stormwater drainage basins which collect stormwater and snowmelt runoff from sources, and discharge to Silver Bow Creek via the storm drain systems. The drainage basins in Butte are Missoula Gulch, Buffalo Gulch, Idaho Street, Anaconda Road/Butte Brewery, West Side, Warren Avenue, Grove Gulch, and the Silver Bow Creek floodplain (CDM, 1991) (Figure 2-2). Runoff and sediment samples collected from these drainages contain elevated concentrations of arsenic, cadmium, copper, lead, and zinc (Tables 2-3 and 2-4).

Most sources in the Butte Priority Soils Operable Unit (BPSOU) are contained within the Missoula Gulch and Buffalo Gulch drainages, which transport runoff from Walkerville and the uptown Butte area to Silver Bow Creek (CDM, 1991). The upper portion of Missoula Gulch has been extensively disturbed by past mining activities and erosion of waste rock dumps in the drainage is visually evident (CDM, 1991). Surface runoff containing hazardous substances is released from Missoula Gulch directly to Silver Bow Creek.

Table 2-2
Hazardous Substance Concentrations at Mill Sites and Waste Rock Dumps in the Butte Area
(total concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	Arsenic	Cadmium	Copper	Lead	Zinc
Mill Sites[2] (Horizon "A")	Arithmetic Mean	457.2	33.1	1,248.9	3,647.3	6,166.2
	Maximum	3,560	294	8,600	58,300	53,300
	Minimum	23	1.7	47	55	127
Mill Sites (Horizon "B")	Arithmetic Mean	597.3	21.7	971.8	2,168.2	4,390.8
	Maximum	4,830	128	5,820	14,700	26,000
	Minimum	14	1.5	28.9	21	100
Mill Sites (Horizon "C")	Arithmetic Mean	448.4	17	1,105.1	1,611.1	3,989.9
	Maximum	6,090	106	11,200	9,440	30,300
	Minimum	15	3.2	35.4	14.1	154
Waste Rock Dumps[3] Unreclaimed (Horizon "A")	Arithmetic Mean	232.6	21.7	805.3	3,127.4	4,399.2
	Maximum	1,400	105	5,680	19,500	23,700
	Minimum	7.8	1.4	35.6	33.3	70.8
Waste Rock Dumps Unreclaimed (Horizon "B")	Arithmetic Mean	387.7	20.4	941.5	3,709.2	6,135.9
	Maximum	3,090	41	8,020	10,200	11,800
	Minimum	32	<0.8	23.7	39.5	855
Waste Rock Dumps Unreclaimed (Horizon "C")	Arithmetic Mean	172.3	21.3	427.1	3,343	5,028.0
	Maximum	588	83	2,330	14,700	11,000
	Minimum	30.1	1.4	14.9	36	95.9
Waste Rock Dumps[4] Reclaimed (Horizon "A")	Arithmetic Mean	158.2	10.2	769.7	681.9	2,609.5
	Maximum	2,430	30	6,210	2,560	9,390
	Minimum	3.1	3.4	60	18.5	117
Waste Rock Dumps Reclaimed (Horizon "B")	Arithmetic Mean	295.4	9	536.7	586.5	1,564.8
	Maximum	2,020	19.8	2,380	2,480	4,340
	Minimum	18.3	2.8	35	45.7	139
Waste Rock Dumps Reclaimed (Horizon "C")	Arithmetic Mean	307.2	15.2	1,273.5	1,641.4	3,939.7
	Maximum	1,150	28.8	5,220	6,140	8,060
	Minimum	15.4	1.1	23	17	97.7
Drainages[5] (Horizon "A")	Arithmetic Mean	101.8	7.1	482.7	883.5	1,973.8
	Maximum	217.0	15.7	1,460	2,310.0	4,650
	Minimum	42	<2	125	123	213

1 CDM, 1988. (Horizon "A": 0-1" or 0-6"; Horizon "B": 1-12" or 6-12"; Horizon "C": 12-24").

2 Mill sites include: Anaconda Sampling Works, Bluebird Mill, Burlington Mill, Butte Sampling Works, Colorado Smelter, Colorado Stamp Mill, Dexter Mill, Driggs and Oregon St., East of Substation, Grove Gulch Mill, Humane Society Mill, Kaw and George St., Lexington Mill, Margaret Ann Mill, Moulton Mill, Old Lexington, Parrot Smelter, Pittsmont Smelter, Timber Butte Mill, Timber Butte Tailings, Washoe Sampling Works, Wee Concentrator Area, other locales (tracks and drainages, old railroad east of Timber Butte, eroded slope).

3 Unreclaimed waste rock dumps include: Alice Dump, Alliance, Amy, Anglo-Saxon, Anselmo (unreclaimed), Atlantic, Bell, Brewer Claim (north of), Charmer, Childe Harold, Colorado Leonard, Corra, Corra-2, Crusher Area Mines, East Gray Rock, Evaline Dump, Garibaldi, Glengarry Dump, Goldsmith (incline), Green Copper Disk, Heaney, Hibernia, Kelley, Laplata, Late Acquisition, Lexington Dump, Little Mina, Little Sarah Claim, Magna Carta, Minnie Irvine, Minnie Jane, Missoula NW Project, Moose, Mountain Con-1, Mountain Con (east of), Nettie, Nettie-2, Nonsuch Fraction, Oden, Old Glory (incline), Old Glory West, Ophir, Orphan Boy, Parrot (east and west sides), Paymaster, Penrose, Prospector, Rising Star, Robert Emmett, Rock Island, Sankey, Silver Queen, Steward, Syndicate Pit (waste north of), Tension, Travona, Venus Claim, Walkerville Landfill, Walkerville (northwest of), Williamsburg.

4 Reclaimed waste rock dumps include: Anselmo (reclaimed), Bonanza, Clear Grit, Colorado, Emma, Downey-1 (New Era), Gagnon, Henry and Quartz St., Missoula Mines, Mountain Con-2, National, New Era, Original, Ravin, Tom Gray, Tom Gray and West, West Gagnon, West Gray Rock.

5 Drainages include stormwater sewer and surface water drainages (See Table 2-3).

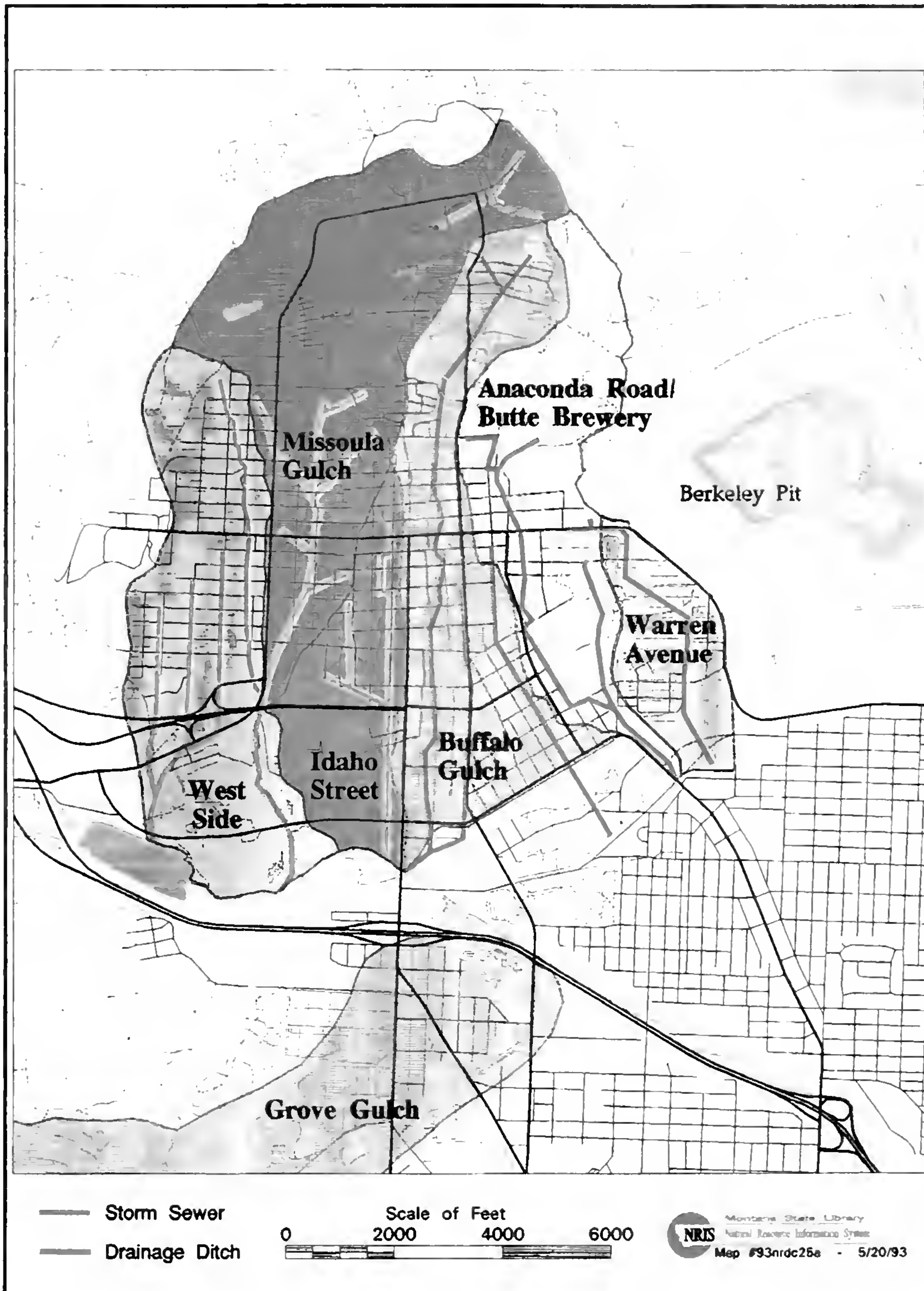

Figure 2-2. Butte Area Stormwater Basins.

Table 2-3
Concentrations of Hazardous Substances in Sediments of Butte Area Drainages
(concentrations in mg/kg dry weight)[1]

Drainage Location	Arsenic	Cadmium	Lead
Buffalo Gulch north of O'Neill St.	65	15.7	2,310
Buffalo Gulch at Ruby St.	106	12	2,100
Missoula Gulch	48.9	7.8	1,480
Laplata St.	138	6.6	1,130
Anaconda storm sewer outfall	217	8	715
Buffalo storm sewer outfall	113	4.6	708
Warren storm sewer outfall	76	9	421
Missoula Gulch storm sewer outfall	53	7	385
Idaho storm sewer outfall	141	0	216
Beef Straight Gulch	120	4.44	131
Westside storm sewer outfall	42	0	123

1 Source: CDM, 1988 as cited in CDM, 1991.

Table 2-4
Concentrations of Hazardous Substances in Source Runoff to Silver Bow Creek
(concentrations in μg/l total)

Source (Receiving Stream)	Cd	Cu	Pb	Zn
Missoula Gulch (to Silver Bow Creek)				
Snowmelt runoff March 10, 1989[1]	26	611	334	2,190
Storm event May 29, 1985[3]	146	4,020	875	21,300
SBC RI monitoring December 3, 1984[3]	14	916	75	4,340
SBC RI monitoring April 8, 1985[3]	2.9	424	444	2,200
Kaw Avenue Storm Drain (to Metro Storm Drain)				
Snowmelt runoff March 10, 1989[1]	5	593	267	1,160
Storm event May 29, 1985[3]	25	1,490	448	3,790
Harrison Avenue Storm Drain (to Metro Storm drain)				
Snowmelt runoff March 10, 1989[1]	19	2,070	454	3,810
Weed Concentrator Complex (to Metro Storm Drain)				
Snowmelt runoff March 10, 1989[1]	90	17,400	454	16,800
Metro Storm Drain (to Silver Bow Creek)				
Snowmelt runoff March 10, 1989[1]	31	2,290	336	3,040
Base flow sampling September 1988[2]	21	311	5.1	7,370
Storm event May 29, 1985[3]	89	10,600	1,500	9,970
SBC RI monitoring December 3, 1984[3]	36	728	150	1,320
SBC RI monitoring April 8, 1985[3]	3.4	953	13	5,980
SBC RI monitoring July 22, 1985[3]	12	327	9.8	6,260

1 CH_2M Hill and Chen-Northern, 1990.
2 PTI, 1989.
3 MultiTech, 1987d, 1987e.

The Buffalo Gulch storm drain begins in the residential area northeast of Walkerville, and follows the historic drainage course. Between Walkerville and south Centerville, the drainage channel contains barren waste rock dumps, some of which are extensively eroded.

The Warren Avenue basin drains the east side of Butte, and discharges to the Metro Storm Drain. Sources of hazardous substances which are contained in the Warren Avenue drainage include mine waste dumps, the Belmont and other inactive mines, and waste rock dumps (CDM, 1991). Water quality sampling (CH_2M Hill and Chen-Northern, 1990; Multitech, 1987, as cited in CDM, 1991) indicated that the water discharged from the Warren Avenue System contained elevated concentrations of metals and arsenic. The apparent sources of these hazardous substances are the mine waste dumps in the drainage (CDM, 1991).

The Anaconda Road-Butte Brewery storm sewer drains industrial and commercial areas adjacent to uptown Butte, and discharges to the Metro Storm Drain at Harrison Avenue. The drainage area contains numerous inactive mines and associated waste dumps; eroded mine wastes have been observed in the drainage (CDM, 1991).

Overall:

- Over 100 separate waste dumps, rock dumps, mine and mill sites, and other areas of contamination have been identified in the Butte area. Waste mine dumps at inactive mines alone are estimated to contain approximately 10,000,000 cubic yards of material contaminated with hazardous substances (Hydrometrics, 1983).

- Elevated concentrations of hazardous substances have been measured in the sediments of various drainages which transport runoff from the Butte area (CDM, 1988).

- Elevated concentrations of hazardous substances have been measured in runoff from numerous surface drainages and underground storm drains which discharge to Silver Bow Creek (CH_2M Hill and Chen-Northern, 1990; PTI, 1989; MultiTech, 1987d, 1987e).

2.2.3 Parrot Tailings Impoundment and Dispersed Tailings in the Metro Storm Drain Area

Historic photographs (circa 1955) show extensive tailings deposits in the upper MSD area (CH_2M Hill and Chen-Northern, 1990). The Parrot Tailings impoundment covers an area of approximately 30 acres in the upper MSD (MultiTech, 1987a). The Parrot

Tailings have elevated metals concentrations, and represent a significant source of groundwater contamination (MultiTech, 1987a). Large quantities of fill material have been deposited in the area since 1955, covering nearly all previously exposed tailings and slag deposits (CH_2M Hill and Chen-Northern, 1990), including the Parrot Tailings (MultiTech, 1987a).

As much as 20 feet of fill material covers tailings deposits that are as much as 14 feet thick in the upper Metro Storm Drain area (CH_2M Hill and Chen-Northern, 1990). Estimated volumes of waste and mixed waste materials containing hazardous substances in the upper Metro Storm Drain area include 190,000 cubic yards of tailings and mixed alluvium and tailings, 300,000 cubic yards of slag, slag-sand, and gravel, 525,000 cubic yards of waste rock, and 840,000 cubic yards of fill material (CH_2M Hill and Chen-Northern, 1990).

Hazardous substance concentrations in waste and mixed waste materials in the upper and lower Metro Storm Drain areas were characterized during the SBC RI Phase II (Tables 2-5 and 2-6). Elevated concentrations of arsenic, cadmium, copper, lead, and zinc occur in all material types, including underlying materials of organic peat, silt, sand, and soil that have been exposed via pathways from the overlying hazardous substances.

Overall:

- The Parrot Tailings and associated dispersed tailings contain elevated concentrations of arsenic, cadmium, copper, lead, and zinc, as characterized in the Silver Bow Creek Remedial Investigation (CH_2M Hill and Chen-Northern, 1990).

- Hazardous substances are present in concentrations and forms that are readily soluble in water (CH_2M Hill and Chen-Northern, 1990).

- Groundwater recharge to Silver Bow Creek in the Metro Storm Drain area contributes a substantial percentage of the metals load in the creek just below the Metro Storm Drain during low flow: cadmium (99%), copper (25%), lead (53%), and zinc (77%) (MultiTech, 1987d).

2.2.4 Butte Reduction Works Tailings and Dispersed Tailings in the Butte Reduction Works Area

The Butte Reduction Works was built in about 1883 and was operated nearly continuously until about 1911 (HRA, 1983, as cited in U.S. EPA, 1992). Between Montana Street and the Colorado Tailings, slag walls were built to retain tailings generated by the Butte Reduction Works (CH_2M Hill and Chen-Northern, 1990;

Table 2-5
Concentrations of Hazardous Substances in Subsurface Materials of the Upper Metro Storm Drain (Lower Area I Operable Unit)
(total metals concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Covered tailings	Arithmetic mean	326	<2	661	658	1,098
	Maximum	524	7	3,350	1,360	2,650
	Minimum	165	<2	196	133	254
Mixed alluvium and tailings	Arithmetic mean	1,853	<9	8,511	1,555	2,742
	Maximum	5,040	21	34,000	3,040	7,560
	Minimum	148	<2	252	221	465
Transported fill: exposed underlying alluvium	Arithmetic mean	111	3	671	1,032	1,174
	Maximum	182	5	1,590	2,480	1,970
	Minimum	23	2	173	351	527
Transported fill: exposed sand/gravel, slag	Arithmetic mean	471	<2	3,051	994	9,023
	Maximum	851	4	4,890	1,930	13,000
	Minimum	228	<4	842	418	2,170
Transported fill: exposed demolition landfill	Arithmetic mean	78	12	863	2,680	22,400
	Maximum	78	12	863	2,680	22,400
	Minimum	78	12	863	2,680	22,400
Transported fill: waste rock	Arithmetic mean	59	0	279	148	46
	Maximum	113	0	409	198	90
	Minimum	20	0	112	85	19
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	593	<8	5,017	149	1,581
	Maximum	2,870	38	21,900	499	4,370
	Minimum	12	<1	953	35	719
Exposed underlying soils: sand, silt, gravel; upper 2 feet	Arithmetic mean	76	<1	508	54	342
	Maximum	254	2	1,220	73	471
	Minimum	11	<2	91	25	86
Exposed underlying soils: sand, silt, gravel; below 2 feet	Arithmetic mean	19	<1	431	55	482
	Maximum	32	2	1,000	106	1,650
	Minimum	7	<1	79	27	102

1 Source: CH_2M Hill and Chen-Northern, 1990.

Table 2-6
Concentrations of Hazardous Substances in Subsurface Materials of the Lower Metro Storm Drain (Lower Area I Operable Unit)
(total metals concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Mixed alluvium and tailings	Arithmetic mean	406	<9	2,559	509	4,211
	Maximum	818	28	8,560	1,020	10,500
	Minimum	207	<1	303	241	958
Exposed underlying soils: (0-1")	Arithmetic mean	90	<2	501	285	679
	Maximum	126	4	931	573	830
	Minimum	25	<2	89	135	491
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	803	10	5,229	615	3,698
	Maximum	1,410	13	8,960	1,060	7,030
	Minimum	93	8	874	204	1,990
Exposed underlying soils: sand, gravel, silt; upper 2 ft	Arithmetic mean	618	41	6,970	430	4,120
	Maximum	618	41	6,970	430	4,120
	Minimum	618	41	6,970	430	4,120

1 Source: CH_2M Hill and Chen-Northern, 1990.

MultiTech, 1987a). Historical photographs show a series of tailings ponds, now covered up, extending from the Colorado Tailings area to just below Montana Street (MultiTech, 1987b). Approximately 430,000 cubic yards of tailings and mixed tailings and alluvium, and 1,630,000 cubic yards of various types of waste, including manganese flue dust, railroad bed fill, and transported fill lie in the former Silver Bow Creek floodplain (CH_2M Hill and Chen-Northern, 1990). Source materials in the Butte Reduction Works area extend to a depth of 10-15 feet, and hazardous substances have been detected to a depth of 2 feet in underlying soils that have been exposed via pathways (CDM, 1991). Approximately 430,000 cubic yards of tailings and mixed tailings and alluvium, and 1,630,000 cubic yards of various types of waste, fill, and sediment are in this area. Maximum thickness of tailings and alluvium tailings deposits is 17 feet (CH_2M Hill and Chen-Northern, 1990).

Hazardous substance concentrations in subsurface samples of various material types are summarized in Table 2-7. Elevated concentrations of hazardous substances occur in all material types, including underlying materials of organic peat, silt, sand, and soil that have been exposed via pathways from the overlying hazardous substances.

Table 2-7
Concentrations of Hazardous Substances in Subsurface Samples from the Butte Reduction Works Area (Lower Area I Operable Unit)
(total metals concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Covered tailings	Arithmetic mean	1,119	11	4,826	1,213	3,857
	Maximum	3,180	22	22,200	2,620	7,880
	Minimum	12	3	36	87	458
Manganese flue dust	Arithmetic mean	2,070	10	10,500	1,220	4,120
	Maximum	2,070	10	10,500	1,220	4,120
	Minimum	2,070	10	10,500	1,220	4,120
Mixed alluvium and tailings	Arithmetic mean	<1,304	63	8,104	13,259	20,693
	Maximum	3,850	270	24,100	167,000	51,800
	Minimum	<90	3	428	834	3,890
Transported fill: underlying alluvium	Arithmetic mean	89	1	242	324	706
	Maximum	89	1	242	324	706
	Minimum	89	1	242	324	706
Transported fill: sand/gravel, slag	Arithmetic mean	213	18	5,040	2,470	26,500
	Maximum	213	18	5,040	2,470	26,500
	Minimum	213	18	5,040	2,470	26,500
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	926	21	4,410	590	7,680
	Maximum	4,430	65	21,300	924	20,100
	Minimum	32	2	78	95	1,090
Exposed underlying soils: sand, gravel, silt; upper 2 ft	Arithmetic mean	93	5	437	944	2,155
	Maximum	148	5	811	1,600	2,760
	Minimum	39	5	64	287	1,550
Exposed underlying soils: sand, gravel, silt; below 2 ft	Arithmetic mean	131	<8	1,641	231	1,566
	Maximum	727	13	7,200	745	4,000
	Minimum	7	<6	21	10	432

1 Source: CH_2M Hill and Chen-Northern, 1990.

Overall:

- Approximately 1,630,000 cubic yards of wastes containing hazardous substances lie in the former Silver Bow Creek floodplain in Butte.

- Source materials contain extremely elevated concentrations of the hazardous substances arsenic, cadmium, copper, lead, and zinc.

- The inflow of metals and arsenic-laden groundwater from the Butte Reduction Works and the Colorado Tailings contributes substantially to exceedences of both chronic and acute aquatic water quality criteria for copper, zinc, and cadmium in Silver Bow Creek during baseflow and low flow conditions (CH_2M Hill and Chen-Northern, 1990; MultiTech, 1987, as cited in U.S. EPA, 1992).

2.2.5 Colorado Tailings Impoundment and Dispersed Tailings

The Colorado Smelter was constructed in approximately 1878 and operated until 1904, during which time tailings generated by its operation were deposited in the Silver Bow Creek floodplain (U.S. EPA, 1992). The deposit, which covers approximately 40 acres, consists of relatively continuous tailings material up to 4.5 feet deep, and additional fill material which covers underlying sediments and alluvium to a depth of 18 feet. Approximately 230,000 cubic yards of tailings and mixed tailings and alluvium, and 580,000 cubic yards of additional fill material are present in the Colorado Tailings (CH_2M Hill and Chen-Northern, 1990). Covered tailings, mixed alluvium and tailings, and underlying organic soils exposed via pathways contain elevated concentrations of hazardous substances (Table 2-8).

Dispersed tailings are located along Silver Bow Creek for approximately one-half mile downstream of the Colorado Tailings. The creek channel has been extensively altered and channelized in the eastern half of this area. In the western half of this area, there is extensive evidence of fluvially deposited tailings adjacent to Silver Bow Creek and within associated meander channels (CH_2M Hill and Chen-Northern, 1990). Hazardous substance concentrations of various material types are summarized in Table 2-9.

A shallow groundwater system is present throughout the year beneath the Colorado Tailings. Groundwater movement through the tailings is generally from the southeast to the northwest, eventually discharging to Silver Bow Creek (Duaime *et al.*, 1985). The base water table elevation is generally two to five feet below the tailings surface and appears to fluctuate in response to the water surface elevation of Silver Bow Creek (MultiTech, 1987a). Duaime *et al.* (1984, as cited in MultiTech, 1987a) reported that groundwater quality in the Colorado Tailings degrades significantly from southeast to northwest, the direction of groundwater flow within the tailings.

Table 2-8
Concentrations of Hazardous Substances in Subsurface Materials from the Colorado Tailings Area (Lower Area I Operable Unit) (total metals concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Covered tailings	Arithmetic mean	1,089	11	5,989	1,152	4,052
	Maximum	2,500	23	16,700	3,280	7,680
	Minimum	553	2	123	268	808
Mixed alluvium and tailings	Arithmetic mean	1,175	22	5,544	2,501	10,685
	Maximum	2,900	55	14,400	6,640	22,000
	Minimum	451	2	586	258	1,030
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	841	<39	9,389	799	10,505
	Maximum	2,910	113	25,600	2,990	31,800
	Minimum	35	<4	355	40	257
Exposed underlying soils: sand, gravel, silt; upper 2 ft	Arithmetic mean	134	<2	1,102	253	1,463
	Maximum	320	5	2,030	652	3,830
	Minimum	32	<5	136	50	253
Exposed underlying soils: sand, gravel, silt; below 2 ft	Arithmetic mean	713	<1	534	21	188
	Maximum	1,420	1	978	32	290
	Minimum	6	<1	90	11	86

1 Source: CH_2M Hill and Chen-Northern, 1990.

Table 2-9
Concentrations of Hazardous Substances in Subsurface Materials from the Area West of Colorado Tailings (Lower Area I Operable Unit) (total metals concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Mixed alluvium and tailings	Arithmetic mean	269	<3	1,626	3,246	3,942
	Maximum	529	7	4,270	6,700	8,120
	Minimum	12	<5	17	9	70
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	104	8	575	1,340	3,690
	Maximum	104	8	575	1,340	3,690
	Minimum	104	8	575	1,340	3,690
Exposed underlying soils: sand, gravel, silt; upper 2 ft	Arithmetic mean	69	7	934	1,276	2,065
	Maximum	83	7	1,320	1,610	2,200
	Minimum	54	6	548	941	1,930
Exposed underlying soils: sand, gravel, silt; below 2 ft	Arithmetic mean	15	<0	202	33	162
	Maximum	15	0	202	33	162
	Minimum	15	<0	202	33	162

1 Source: CH_2M Hill and Chen-Northern, 1990.

Overall:

- The Colorado Tailings contain elevated concentrations of arsenic, cadmium, copper, lead, and zinc (CH_2M Hill and Chen-Northern, 1990).

- Hazardous substances are present in concentrations and forms that are readily soluble in water (CH_2M Hill and Chen-Northern, 1990).

- The Colorado Tailings contribute substantial amounts of hazardous substances to the local groundwater which discharges into Silver Bow Creek (MultiTech, 1987a, 1987d). Hazardous substances have been measured in Colorado Tailings groundwater at concentrations as high as 5,000 $\mu g/l$ (arsenic), 790 $\mu g/l$ (cadmium), 98,000 $\mu g/l$ (copper), 180 $\mu g/l$ (lead), and 240,000 $\mu g/l$ (zinc) (CH_2M Hill and Chen-Northern, 1990).

- Groundwater recharge from the Colorado Tailings contributes a significant proportion of the copper and zinc loadings to Silver Bow Creek (Duaime *et al.*, 1990, as cited in U.S. EPA, 1992).

- Samples of surface runoff collected from the Colorado Tailings contain extremely elevated concentrations of hazardous substances. Hazardous substances in surface runoff have been measured at concentrations as high as 928 $\mu g/l$ (cadmium), 233,000 $\mu g/l$ (copper), 161 $\mu g/l$ (lead), and 282,000 $\mu g/l$ (zinc). These concentrations are orders of magnitude greater than federal ambient water quality criteria (see Chapter 4.0).

2.2.6 Fluvially Deposited Streamside Tailings

Contaminated sediments transported in Silver Bow Creek have been deposited on Silver Bow Creek floodplains as a result of increased sediment loading and channel aggradation[1] during high water events, and as a result of downstream erosion and re-deposition of contaminated material.

The addition of large quantities of sediment and mine wastes to Silver Bow Creek resulted in aggradation of the river channel. The decreased riverbed volume caused frequent flooding (GCM Services, Inc., 1983, as cited in MultiTech, 1987b) and accelerated river meandering as the increased sediment load clogged the channel. The channel clogging resulted in the development of a braided stream pattern which

[1] Modification of the channel bed in the direction of uniformity of grade by deposition; in this case, "filling in" of the channel.

progressed downstream. Former stream channels are evident in aerial photographs as deposits of fine grained sediment and tailings devoid of vegetation.

Streamside tailings along Silver Bow Creek are subject to erosion and entrainment during high flows. Contributions of arsenic, copper, lead, and zinc from channel or bank material during higher flows is significant in reaches from the Colorado Tailings to Silver Bow, and from Ramsay Flats to Fairmont Hot Springs (MultiTech, 1987d). Re-entrainment and transport of streamside tailings constitutes a continuing release of hazardous substances; hazardous substances in floodplain sediments will be gradually transported downstream.

As a result of hazardous substance releases to and transport within Silver Bow Creek, suspended, bank, and bed sediments throughout the creek are contaminated with hazardous substances relative to baseline (see Chapter 3.0). Currently, the entire Silver Bow Creek floodplain is contaminated with fluvially deposited mixtures of mill tailings, mine waste, and sediment (CH_2M Hill and Chen-Northern, 1990).

Peckham (1979) estimated that approximately 1,700,000 cubic meters (2,300,000 cubic yards) of mine tailings containing 9,000,000 kilograms (20,000,000 pounds) of copper and 18,000,000 kilograms (39,000,000 pounds) of zinc were deposited along Silver Bow Creek. Canonie (1992) estimated that 3,700,000 to 7,800,000 cubic yards of tailings and tailings-impacted material are contained within the Streamside Tailings Operable Unit (below the Colorado Tailings to Warm Springs). Between the Colorado Tailings and Durant Canyon, approximately 1,700,000 to 4,100,000 cubic yards of tailings and mixed tailings and alluvium were deposited. The most prominent feature of this reach is Ramsay Flats, a 160-acre fluvial deposit of barren tailings and mixed tailings and alluvium. Between the upstream end of Durant Canyon and Finlen, an estimated 733,000 to 965,000 cubic yards of tailings and mixed tailings and alluvium were deposited. Between Finlen and the Warm Springs Ponds, an estimated 1,300,000 to 2,800,000 cubic yards of tailings and mixed tailings and alluvium were deposited (Canonie, 1992). In Silver Bow Creek alone, the surface area of tailings has been estimated at 1,270 acres (Hydrometrics, 1983) (see Figure 2-3).

Chemical analysis of floodplain materials from Silver Bow Creek indicates that tailings contain elevated concentrations of hazardous substances and low pH. The presence of hazardous substances in tailings deposits and riparian soils has been confirmed by many studies (e.g., MSU *et al.*, 1989; Rice and Ray, 1984; MultiTech, 1987a; CH_2M Hill and Chen-Northern, 1990; Peckham, 1979). All data indicate that the tailings deposits and soils impacted by tailings have extremely elevated concentrations of arsenic, cadmium, copper, lead, and zinc (Table 2-10).

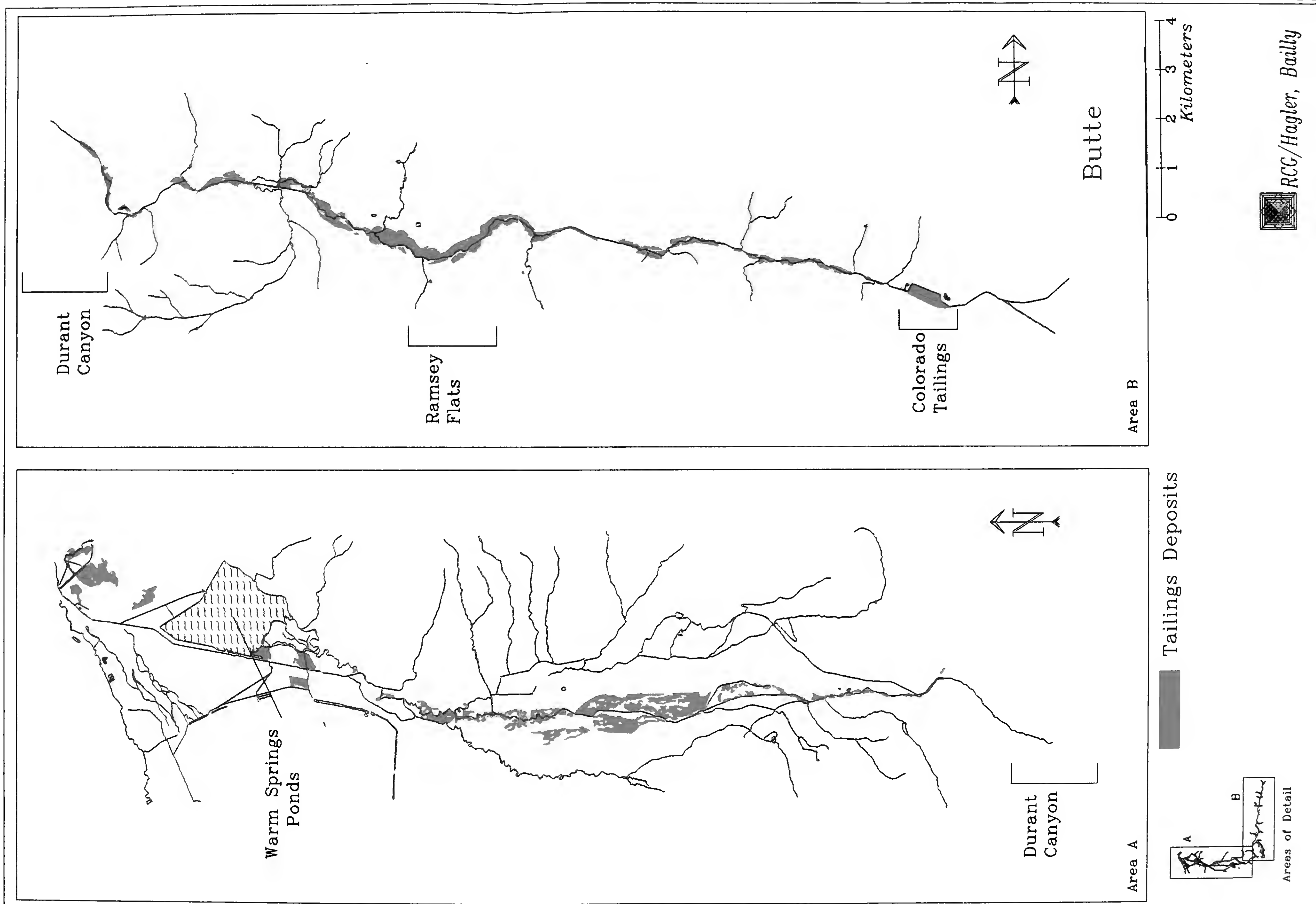

Figure 2-3. Floodplain Tailings Deposits, Silver Bow Creek.

Table 2-10
Average Total Metals and Arsenic Concentrations in Tailings and Floodplain Sediments of Silver Bow Creek
(concentrations in ppm)

Location on Silver Bow Creek	As	Cd	Cu	Pb	Zn	(n)
Montana Street to the Upper Metro Storm Drain[1]						
► Exposed tailings	601	9	1,523	644	2,854	14
► Flue dust	761	15	477	2,645	4,510	2
► Floodplain sediments/mixed alluvium and tailings	306	10	1,936	773	4,217	26
► Waste rock - railway roadbed fill	298	3	1,389	421	857	8
► Waste rock - transported fill and alluvium	113	<4	552	265	1,571	11
► Soil	97	5	570	565	1,101	4
Below Colorado tailings to Miles Crossing[2]	485	6.5	220	1,280	3,970	21
Ramsay Flats	399	13.4	2,350	989	3,070	15
Miles Crossing to Warm Springs Ponds[2]	371	6.2	2,030	1,040	2,920	28
Butte to the Mill-Willow Bypass[4]	678	17.3	2,520	1,480	3,790	35

1 CH_2M Hill and Chen-Northern, 1990.
2 Canonie, 1992.
3 MultiTech, 1987a.
4 MSU *et al.*, 1989.

Overall:

- Elevated concentrations of hazardous substances have been measured in tailings and floodplain sediments by numerous investigators.

- Elevated concentrations of hazardous substances have been measured in surface runoff from Ramsay Flats, the largest barren tailings deposit along Silver Bow Creek (CH_2M Hill, 1987).

- Significant increases in arsenic, copper, lead, and zinc loadings in Silver Bow Creek during high flows from channel or bank material were documented in two reaches (Colorado Tailings to Silver Bow town, Ramsay Flats to Gregson bridge) (MultiTech, 1987d). Metal loads in these two reaches averaged approximately two pounds per day of arsenic, four pounds per day of lead, 23 pounds per day of copper, and 26 pounds per day of zinc.

2.2.7 Montana Pole Treatment Plant Site

The Montana Pole Treatment Plant began operation in 1946. Modifications in 1949 and 1956 included the addition of two retorts for pressure-treating wood with a diesel/pentachlorophenol mixture (Boulton process). Process wastewater was reportedly discharged to a ditch which flowed to Silver Bow Creek. An explosion and fire on May 5, 1969 resulted in spillage of petroleum/PCP product. On May 17, 1984 all operations at the site were discontinued (Keystone, 1991).

Sources of hazardous substances at the Montana Pole Site include spillage (especially from the mixing tanks), drippings from treated wood, leaking pipelines used to transfer products, the drainage ditch that received process wastewater from the plant, the catchment area below the retorts, water discharged from clarifying tanks, the mixing vat, and areas where condensate pooled during discharge (Keystone, 1992e, as cited in ARCO, 1993).

Elevated concentrations of hazardous organic substances have been found in the surface and subsurface soils in the former process area and along the drainage ditches (ARCO, 1993). The highest concentrations of pentachlorophenol (PCP) and other organic compounds in the subsurface were generally found in samples collected at or near the water table.[2] In addition, wells located near Silver Bow Creek contain arsenic, cadmium, copper, lead, and zinc, likely the result of mining-related wastes (ARCO, 1993). Table 2-11 provides a summary of concentrations of hazardous substances in the groundwater underlying and surface water (Silver Bow Creek) adjacent to the Montana Pole Treatment Site.

2.2.8 Rocker Timber Framing and Treating Area

The Rocker Operable Unit of the Silver Bow Creek/Butte Area NPL site is located approximately seven miles west of Butte and is bordered to the north by Silver Bow Creek (Keystone, 1992). The former Rocker Timber Framing and Treating Plant, which treated mine timbers with a preservative containing arsenic, was operated by the Anaconda Company until approximately 1957.

The surface and subsurface soils still contain elevated levels of arsenic. One sample at the 9- to 11-foot sampling interval had an arsenic concentration of 42,900 mg/kg. Elevated levels of cadmium, copper, lead, mercury, and zinc are also present. There are also load increases of total arsenic, copper, and lead between surface water stations

[2] Organic hazardous substances are released to Silver Bow Creek by the site groundwater, as evidenced by the oily seeps observed along the streambank (ARCO, 1993).

Table 2-11
Concentrations of Hazardous Substances in Groundwater and Surface Water at the Montana Pole and Treatment Plant Site
(concentrations in ppb)[1]

Media	Statistical Parameter	Organic Compounds				Inorganic Compounds				
		PCP	PAH	BTEX	2,3,7,8-TCDD or equivalent	As	Cd	Cu	Pb	Zn
Groundwater	Arithmetic mean	3,830	51,770	40	NC	40	20	1,470	NM	5,340
	Maximum	880,000	3,668,691	1,300	0.0537	1,570	232	34,600	NM	75,200
	Minimum	0.5	0.02	0.39	0.0010	0.2	2.5	12.5	NM	10
Surface water	Arithmetic mean	75	9	NM	NM	18	2.5	156	11	614
	Maximum	591	49.53	NM	NM	25.2	2.5	220	30.3	1,120
	Minimum	0.5	0.3	NM	NM	12.9	2.5	93.6	2.5	262

1 Source: Keystone, 1992e, as cited in ARCO, 1993.

Note:
PCP = Pentachlorophenol.
PAH = Polynuclear aromatic hydrocarbons (total).
BTEX = Benzene, toluene, ethylbenzene, xylene (total).
TCDD = Dioxin.

As = Arsenic.
Cd = Cadmium.
Cu = Copper.
Pb = Lead.
Zn = Zinc.

NM = not measured.
NC = not calculable.

located upstream and downstream of the Rocker Operable Unit. Streambed sediments at the Rocker Operable Unit also contain arsenic, cadmium, copper, lead, and zinc (Keystone, 1992)

2.2.9 Solubility of Hazardous Substances in Waste Deposits

The previous sections identified and described general source categories of hazardous substances to Silver Bow Creek. During the SBC RI/FS, 20 surface material samples were analyzed for water soluble substances to evaluate the potential impact of surface runoff on receiving waters. The data indicate that sources contain hazardous substances which readily solubilize in water (Tables 2-12 and 2-13). Runoff collected from exposed surface tailings deposits also contains elevated concentrations of hazardous substances (Table 2-14). The high solubility of these source materials makes them readily released to surface water resources during precipitation.

2.2.10 Pathways of Hazardous Substances from Sources to Silver Bow Creek

This section briefly summarizes pathways by which hazardous substances migrate from sources into the Silver Bow Creek aquatic ecosystem. This section also briefly describes current and ongoing releases of hazardous substances into Silver Bow Creek.

The principal pathways of hazardous substances into Silver Bow Creek are direct physical contact (as described in preceding sections), groundwater, surface water, and sediments. Numerous reports have documented the importance of groundwater as a pathway to Silver Bow Creek. The SBC RI/FS identified contaminated groundwater inflows to Silver Bow Creek in the areas of the Metro Storm Drain (MSD), and between Montana Street (Butte Reduction Works area) and the western end of the Colorado Tailings as a substantial source of cadmium, copper, and zinc. The area of degraded groundwater along the MSD coincides with the location of the historic Silver Bow Creek channel (MultiTech, 1987d), along which the Parrot Tailings were deposited. CDM (1990) concluded that alluvial groundwater is a major pathway for the migration of copper and zinc to Silver Bow Creek in the reach between Montana Street and the Colorado Tailings. U.S. EPA (1992) concluded that alluvial water at Lower Area I flows through the Butte Reduction Works and the Colorado Tailings before discharging to Silver Bow Creek.

Table 2-12
Concentrations of Water-soluble Hazardous Substances in Surface Materials (0-1")
(Lower Area I Operable Unit)
(total metals concentrations in $\mu g/l$)[1]

Area	Material Unit	As	Cd	Cu	Pb	Zn
Upper Metro Storm Drain	Mixed tailings and alluvium	46	100	41,000	<0.4	21,000
	Railway roadbed fill	3,900	89	27,000	1.8	25,000
	Transported fill (sand, gravel with slag, waste rock)	15	370	730	<0.4	86,000
Lower Metro Storm Drain	Mixed tailings and alluvium	7.1	220	3,300	<0.4	92,000
	Mixed tailings and alluvium	25	280	750	<0.4	110,000
	Mixed tailings and alluvium	110	<0.1	40	<0.4	40
	Mixed tailings and alluvium	3.8	22	1,300	1.3	27,000
	Mixed tailings and alluvium	9.2	100	57	<0.4	26,000
	Mixed tailings and alluvium	130	0.11	91	0.8	21
	Mixed tailings and alluvium	3.8	10	98	<0.4	1,400
Butte Reduction Works	Exposed tailings	3.7	470	370,000	<0.4	150,000
	Covered tailings	8,900	1,800	900,000	<0.4	660,000
	Manganese flue dust	9.3	<0.1	<6	<0.4	86
	Railway roadbed fill	12	26	8,100	1.3	21,000
	Railway roadbed fill	20	2,000	42,000	6.7	670,000
Colorado Tailings	Exposed tailings	34	<0.1	7.0	<0.4	20
	Transported fill	9.8	360	150	<0.4	39,000
West of Colorado Tailings	Mixed alluvium and tailings	12	350	23,000	<0.4	70,000

1 Source: CH_2M Hill and Chen-Northern, 1990.

Table 2-13
Concentrations of Water-soluble Hazardous Substances In Subsurface Materials
(Lower Area I Operable Unit)
(total metals concentrations in $\mu g/l$)[1]

Material Unit	Depth (ft)	As	Cd	Cu	Pb	Zn
Upper Metro Storm Drain						
Mixed tailings and alluvium	1.3 - 2.5	260	290	820,000	<0.4	33,000
Transported fill: sand/gravel, slag	2.0 - 5.5	<3	73	270	4.8	20,000
Covered tailings	22 - 25.3	140	1.8	1,700	8	640
Lower Metro Storm Drain						
Mixed tailings and alluvium	0 - 1.2	4.9	66	660	<0.4	11,000
Mixed tailings and alluvium	1.7 - 2.4	5.3	0.72	140	2.2	310
Butte Reduction Works						
Covered tailings	2.8 - 3.7	16	240	520,000	2.0	100,000
Covered tailings	2.0 - 3.5	24	40	300	10	14,000
Mixed tailings and alluvium	6.0 - 9.5	18	180	6.0	800	23,000
Mixed tailings and alluvium	0.8 - 2.8	23	4,100	330,000	15	740,000
Colorado Tailings						
Covered tailings	2.4 - 2.8	86	120	170,000	5.4	39,000
Covered tailings	1.0 - 3.0	23	31	180,000	9.8	7,000
Exposed underlying soil: organic silts, clays, peat	1.5 - 2.5	9.5	330	100	0.9	22,000

1 Source: CH_2M Hill and Chen-Northern, 1990.

Table 2-14
Concentrations of Hazardous Substances in Surface Runoff from Tailings Deposits to Silver Bow Creek
(concentrations in $\mu g/l$ total recoverable)

Source (Receiving Stream)	Cd	Cu	Pb	Zn
Colorado Tailings (to Silver Bow Creek)				
Snowmelt runoff March 10, 1989[1]	74	21,100*	87	27,200
Storm event runoff July 8, 1986[2]	928	233,000	161	282,000
Ramsay Flats (to Silver Bow Creek)				
Storm event runoff July 16, 1986[2]	1250	202,000	3100	264,000

* Indicates acid soluble concentration.
1 CH_2M Hill and Chen-Northern, 1990.
2 CH_2M Hill, 1987.

Surface water is the primary pathway by which hazardous substances migrate from sources in the Butte area to downstream reaches in Silver Bow Creek and the Clark Fork River. The two predominant mechanisms by which surface water functions as a pathway are riverine transport and surface runoff. Flowing water transports suspended and dissolved hazardous substances from upstream to downstream. This pathway is particularly important during periods of high flow, when releases from bed and channel sediments are most important (MultiTech, 1987d). Thus, both surface water and sediments serve as pathways. In addition, surface runoff erodes and transports hazardous substances (either dissolved or adsorbed to sediment) from source areas to surface water. The importance of this pathway is evident in the concentrations of hazardous substances which have been documented in runoff from streamside tailings and from storm drain discharges in Butte (see Chapter 4.0).

2.3 SOURCES OF HAZARDOUS SUBSTANCES TO THE CLARK FORK RIVER

Silver Bow Creek is the primary source from which hazardous substances have been, and continue to be released to the Clark Fork River. Silver Bow Creek transports hazardous substances from sources in the Butte area and from streamside tailings to the Warm Springs Ponds and, ultimately, to the Clark Fork River. Therefore, all sources of hazardous substances to Silver Bow Creek are sources to the Clark Fork River via the Warm Springs Ponds. Additional sources of hazardous substances to the Clark Fork

River include the Warm Springs Ponds themselves, sources in the Anaconda area related to the past operation of the Anaconda Smelter, the Opportunity Ponds (a repository for the Anaconda smelter tailings), riverside tailings along the Clark Fork River which contain significantly elevated concentrations of hazardous substances, and discharges from the Anaconda Smelter. These sources are described in the following subsections.

2.3.1 Warm Springs Ponds

The Warm Springs Ponds were designed to collect mining-related wastes and associated contaminated sediments transported by Silver Bow Creek from sources in the Butte area. Ponds 1 and 2 were constructed prior to 1920; Pond 3 was constructed between 1954 and 1959, primarily for sediment control (Hydrometrics, 1983a, as cited in MultiTech, 1987c). The Warm Springs Ponds contain an estimated 18,960,000 cubic yards (MDHES and CH_2M Hill, 1989) of sediment containing elevated concentrations of hazardous substances (Table 2-15) (MDHES and CH_2M Hill, 1989).

Table 2-15
Average Concentrations of Hazardous Substances in Pond Bottom Sediments
(total metals concentrations in mg/kg dry weight)[1]

Location	Statistical Parameter	As	Cd	Cu	Pb	Zn
Pond 1	Arithmetic mean	408	10	2,886	670	2,212
	Maximum	17	66	9,390	1,920	7,900
	Minimum	7	1	19	8	70
Pond 2	Arithmetic mean	590	36	4,661	726	4,859
	Maximum	1,910	291	15,700	1,670	28,200
	Minimum	10	1	62	10	49
Pond 3	Arithmetic mean	301	195	7,015	252	17,319
	Maximum	1,630	659	16,400	680	45,800
	Minimum	18	1	107	9	114
Wildlife Ponds	Arithmetic mean	42	8	439	54	855
	Maximum	94	20	1,160	126	2,380
	Minimum	12	1	50	54	77
Baseline[2]	Minimum	7	0.22	20	15.4	56.5

1 Source: MDHES and CH_2M Hill, 1989.
2 See Chapter 3.0.

Hazardous substances in the Warm Springs Ponds are released to the Clark Fork River through the Pond 2 discharge or by recharge of the underlying contaminated groundwater to the Clark Fork River and the Mill-Willow Bypass. Concentrations of copper, lead, and zinc in the Pond 2 discharge regularly exceed aquatic life criteria (Table 2-16). Extremely elevated concentrations of copper continue to be released from the Warm Springs Ponds. For example, copper concentrations as high as 125 ppb and zinc concentrations as high as 310 ppb were measured in the Pond 2 discharge in the Spring of 1993 (U.S. EPA, 1993). Further, the U.S. EPA (1993) notes that these values were exceeded in 1992, when copper and zinc concentrations as high as 338 ppb and 533 ppb, respectively, were measured. These values are roughly 10 and 3 times the acute water quality criteria for copper and zinc, respectively (see Chapter 4.0).

Table 2-16
Concentrations of Hazardous Substances in the Warm Springs Pond 2 Discharge
(total recoverable concentrations in ppb)[1]

	Cd		Cu		Pb		Zn	
Year	Range	Median	Range	Median	Range	Median	Range	Median
1983	NA	NA	<10 - 190	35	NA	NA	20 - 260	90
1984	NA	NA	<10 - 120*	20	NA	NA	20 - 470	120
1985	NA	NA	<10 - 100**	30	NA	NA	15 - 495	132
1986	NA	NA	<10 - 160*	30	NA	NA	19 - 693*	54
1987	NA	NA	<10 - 40*	20	NA	NA	7 - 191	43
1988	<.2 - .3	<.2	3 - 30**	10	<1 - 4	<1	6 - 156	51
1989	<.2 - .2	<.2	7 - 210*	20	<1 - 55**	2	10 - 576*	58
1990	<.2 - .4	<.2	6 - 57*	16	<1 - 10**	1	4 - 115	40
1991	<.2 - .9	.4	16 - 49*	24	1 - 52**	4	43 - 118	61

1 Source: STORET; MDHES, 1990, 1991.
* Range of concentrations includes at least one acute criteria exceedence.
** Range of concentrations includes at least one chronic criteria exceedence.

There also have been numerous seepages containing arsenic, copper, lead, and zinc from the Warm Springs Ponds directly to the Clark Fork River and Mill and Willow Creeks (Spindler, 1971; Anaconda Company, 1972).

2.3.2 Anaconda Area Waste Deposits

Warm Springs Creek flows approximately three miles through the Old Works Operable Unit (PTI, 1991) before joining the Clark Fork River. Tailings and other wastes associated with the operation of the Old Works were placed along the Warm Springs Creek channel. Waste deposits and sources described in the Old Works Engineering Evaluation/Cost Analysis (EE/CA) preliminary site characterization information (PTI, 1991) include Waste Piles 1-8, Old Works structural area, heap roast slag, floodplain wastes, red sands, and waste ponds (Figure 2-4). These source areas all contain elevated concentrations of hazardous substances (Table 2-17).

Waste materials along Warm Springs Creek were evaluated during the Anaconda Smelter RI/FS (Tetra Tech, 1987) and the Old Works EE/CA (PTI, 1991). Various wastes, including jig tailings, mixed slag, brick rubble, urban waste, and debris were deposited in the Warm Springs Creek floodplain during the operating period of the Old Works (PTI, 1991). These floodplain wastes total approximately 440,000 cubic yards (PTI, 1991).

Other waste volumes include approximately 298,390 cubic yards of heap roast slag, 606,700 cubic yards of Red Sands, and 8,050 cubic yards of material in the Waste Ponds. These waste deposits contain elevated concentrations of the hazardous substances (Table 2-17). Hydraulic modeling of Warm Springs Creek conducted for the Old Works EE/CA data summary report indicated that erosion of hazardous substances from the Red Sands area is predicted to occur during medium to high flows. In addition, backwater flooding over tailings deposits located upstream of the city dump road bridge is predicted during a 100 year flood. Exposed tailings also occur on or behind streambank levees. PTI (1991) concluded, "the location of these waste deposits adjacent to the stream and levels of the predicted 100 year flood indicate that erosion and transport may occur during very high flows." Elevated concentrations of hazardous substances have been documented in Warm Springs Creek downstream of the Old Works area (Ingman and Kerr, 1990b). ESE, Inc. (1991) measured exceedences of copper and lead criteria in Warm Springs Creek downstream of the Old Works area. Samples collected upstream did not exceed criteria.

2.3.3 Opportunity Ponds

The Opportunity Ponds contain approximately 435,000,000 cubic yards of tailings generated by the Anaconda Smelter (Tetra Tech, 1987). Hazardous substances contained within these ponds are released to Warm Springs Pond 3 by two discharges (North and South Opportunity Ponds Decant Ditches). Hazardous substances are also released to the underlying groundwater aquifer, resulting in a plume containing elevated concentrations of hazardous substances. Contaminated groundwater, in turn, recharges to several drains which border the Opportunity Ponds. These drains transport the

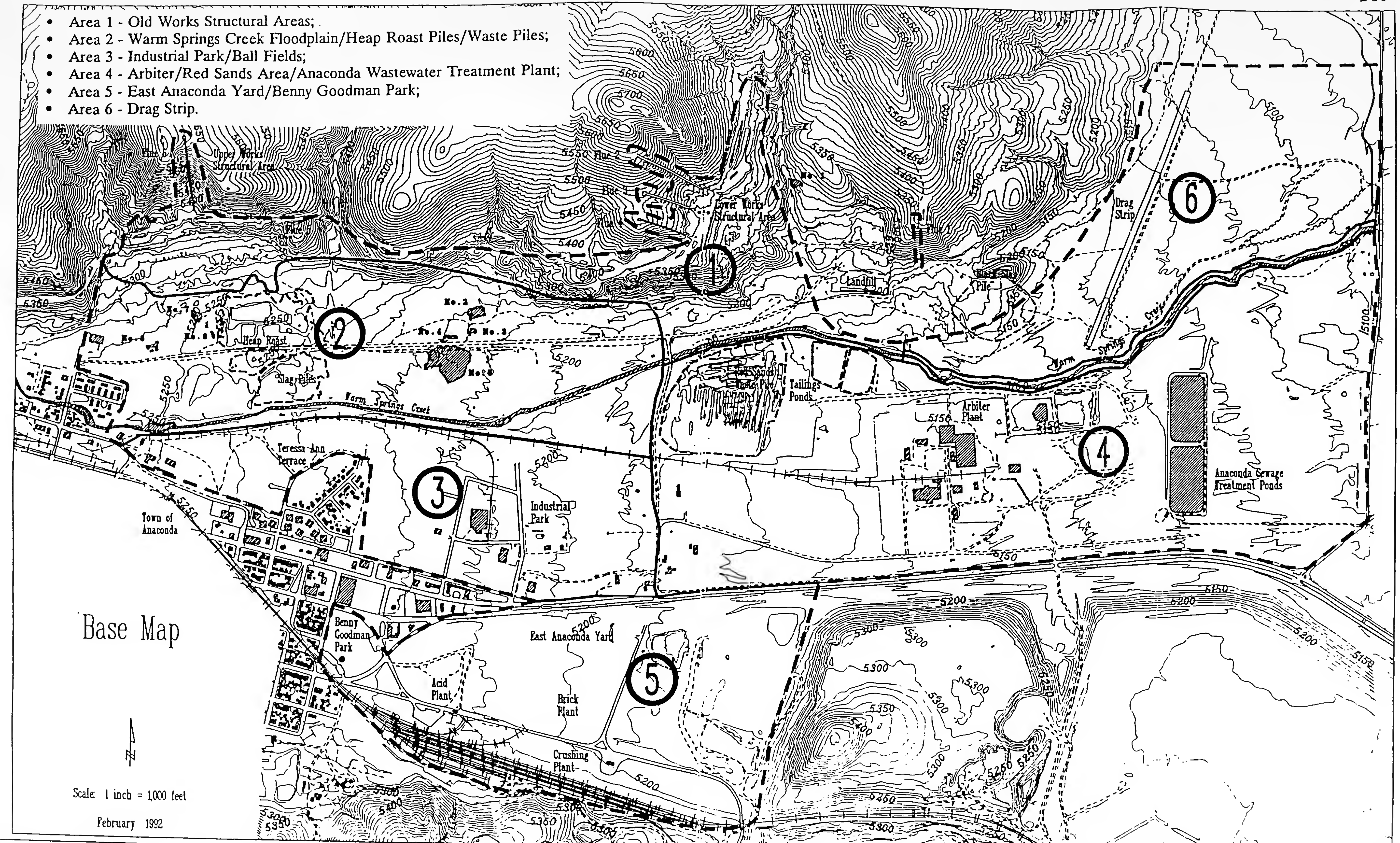

Figure 2-4. Old Works Area Waste Deposits Along Warm Springs Creek.

Table 2-17
Concentrations of Hazardous Substances in Old Works Area Waste Deposits
(total metals concentrations in mg/kg)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Waste Piles 1-8,[2] all samples	Arithmetic mean Maximum Minimum	1,018 8,110 4.2	2.4 11.2 0.4	7,791 32,100 22.2	185.1 990 8.4	532 1,660 51
Upper Works structural area,[2] all samples	Arithmetic mean Maximum Minimum	445.3 1,340 26.1	7.0 20 0.85	5,208 19,800 35.9	243.1 1,740 8.5	3,416 39,800 25.6
Heap Roast Slag[2] all samples	Arithmetic mean Maximum Minimum	759.3 7,120 6.7	3 18.8 0.6	8,212 59,200 878	321.7 737 5	5406 15,000 131
Heap Roast Slag[3] all samples	Arithmetic mean Maximum Minimum	958.5 1,007 910	13.1 13.4 12.8	6,550 7,000 6,100	1,008 1,030 985	17,750 18,100 17,400
Floodplain[2] all samples	Arithmetic mean Maximum Minimum	1,084 7,100 1.9	5.4 29 0.6	3,093 25,000 30	287.4 2,900 5	908 19,000 22
Red Sands[3] all samples	Arithmetic mean Maximum Minimum	1,685 2,170 1,200	10.5 13.3 7.7	2,665 3,170 2,160	455 618 292	3,530 4,640 2,420
Waste Ponds[2] all samples	Arithmetic mean Maximum Minimum	3,220 4,750 1,850	6.9 8.4 4.8	3,720 5,450 2,540	1,055 1,690 616	617 882 378

1 Source: PTI, 1991.
2 PTI, 1990, as cited in PTI, 1991.
3 Tetra Tech, 1987, as cited in PTI. 1991.

groundwater recharge to Warm Springs Creek (North Drain Ditch) and to Warm Springs Pond 3 (Decant Ditches).

Concentrations of hazardous substances in the Opportunity Ponds were quantified during the Anaconda Smelter RI/FS, and summarized by Tetra Tech (1987). Metals concentrations in the discharges to Warm Springs Pond 3 were characterized in the Warm Springs Ponds Operable Unit Feasibility Study (MDHES and CH_2M Hill, 1989) (Table 2-18). The North and South Opportunity Ponds discharges, with average flows of 1.3 and 0.97 cfs, respectively, transport hazardous substances from the Opportunity Ponds to Warm Springs Pond 3 (Table 2-19).

2.3.4 Riverside Tailings

Riverside tailings occur in much of the Warm Springs Ponds area and in the upper Clark Fork River, particularly upstream of Deer Lodge (Figure 2-5). Tailings deposits in the Warm Springs Ponds area were characterized in the Warm Springs Ponds Operable Unit Feasibility Study (MDHES and CH_2M Hill, 1989). Tailings deposits and contaminated soils are present below Warm Springs Pond 1 and in the Mill-Willow Bypass (tailings within the Mill-Willow Bypass were removed during reconstruction of the Bypass which began in 1990) (Table 2-20). Tailings within the Bypass most likely originated from the outflows of the Opportunity Ponds, and from tailings transported and deposited by Silver Bow Creek during high flows (MDHES and CH_2M Hill, 1989). Approximately 75,800 cubic yards of tailings and 130,000 cubic yards of contaminated soils were contained in the Bypass before removal. Before reconstruction of the Bypass, exposed tailings were sources of hazardous substances to surface water during high streamflows or by precipitation-induced runoff. During extended dry periods, highly soluble salts of copper and zinc formed through the evaporation of soil moisture on the tailings deposits that existed along the Bypass. The salts were clearly visible during warmer months as blue- and green-colored surface deposits (MDHES and CH_2M Hill, 1989).

An estimated 920,000 cubic yards (704,000 cubic meters) of tailings cover 678 acres (275 ha) in the upper 10 km (6.2 miles) of the Clark Fork River floodplain (Nimick, 1990). Mixtures of cleaner fluvial sediments have been deposited on top of tailings, and tailings are continually cycled back and forth between the channel and the floodplain. An estimated two million cubic meters (2.5 million cubic yards) of contaminated sediment have been deposited on the Clark Fork River floodplain (J.N. Moore, University of Montana, *pers. comm.*, as cited in Axtmann and Luoma, 1991). Axtmann and Luoma, 1991). One study, using existing soils maps and aerial photographs, estimated that 9,000 acres of floodplain soils have been contaminated with hazardous substances (CH_2M Hill *et al.*, 1991). Additional acreage has been exposed to hazardous substances via irrigation with contaminated river water. Hazardous substance concentrations in tailings and floodplain sediments of the Clark Fork River are presented in Table 2-21.

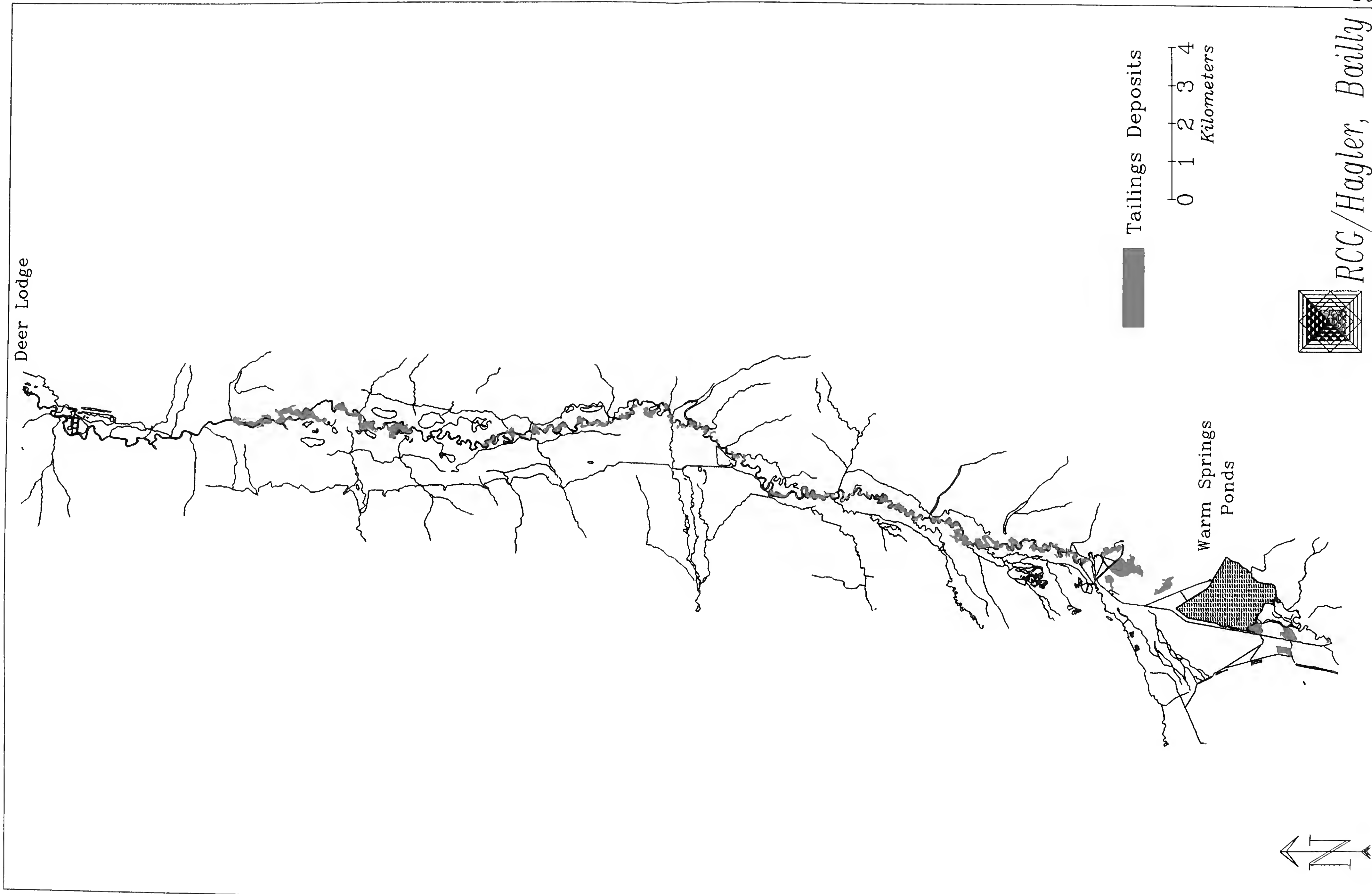

Figure 2-5. Floodplain Tailings Deposits, the Clark Fork River (Warm Springs Ponds to Deer Lodge).

Table 2-18
Average Concentrations of Hazardous Substances in the Opportunity Ponds (concentrations in mg/kg)[1]

Location in Opportunity Ponds	As	Cd	Cu	Pb	Zn
Cell A[2]	370	8.2	2,200	600	1,490
Cell B1[2]	NA	5.4	1,530	440	962
Cell B1[3]	NA	NA	1,760	775	1,250
Cell B2[2]	147	3.6	1,790	380	1,080
Cell B2[3]	NA	NA	2,420	535	1,360
Cell C1[2]	216	5.2	1,970	380	1,570
Cell C1[3]	NA	NA	2,910	890	1,750
Cell C2[2]	238	10.3	2,320	380	960
Cell C2[3]	NA	NA	2,100	310	840
Cell D2[2]	61	<2	1,170	170	700
Cell D2[3]	NA	NA	1,480	265	560

1 Tetra Tech, 1987.
2 Tetra Tech, 1986, as cited in Tetra Tech, 1987.
3 Anaconda Minerals Company, 1981, as cited in Tetra Tech, 1987.

Table 2-19
Concentrations of Hazardous Substances in the Opportunity Ponds Discharges (total concentrations in μg/l)[1,2]

Discharge	As	Cd	Cu	Pb	Zn
North Opportunity Ponds discharge					
Maximum	19	0.6	100	192	1,680
Minimum	NA	NA	NA	NA	35
Average	4	0.1	310	16	198
South Opportunity Ponds discharge					
Maximum	25	0.3	65	129	632
Minimum	NA	NA	NA	NA	63
Average	10	NA	27	11	288

1 MDHES and CH_2M Hill, 1989.
2 NA = parameter not analyzed.

Table 2-20
Average Concentrations of Hazardous Substances In Tailings and Floodplain Sediments of the Warm Springs Ponds Area and the Mill-Willow Bypass
(total metals concentrations in mg/kg dry weight)

Location	As	Cd	Cu	Pb	Zn
Above Pond 3 and below Pond[1]	593	19.1	18,147	394	5,223
Mill-Willow Bypass[1]					
All sediments	121	22	3,713	215	4,258
Metallic salts	NM	NM	19,680	NM	21,266
Baseline[2]	7	0.22	20	15.4	56.5

1 MDHES and CH_2M Hill, 1989.
2 See Chapter 3.0.

Table 2-21
Concentrations of Hazardous Substance in Tailings and Floodplain Sediments of the Clark Fork River
(mg/kg)

Location on the Clark Fork River	As	Cd	Cu	Pb	Zn	(n)
Below Warm Springs Ponds extending 10 km north[1]	769	3.64	4,532	712	1,839	83
North of Warm Springs Ponds[2]	600	5.7	3,662	547.3	2,206	67
Warm Springs Ponds to Deer Lodge[3]	634	8.8	1,760	461	1,160	8
Warm Springs Ponds to Drummond[4]	459	NA	3,328	394	1,834	140
Warm Springs Ponds to Turah[5]	NA	9.3	1,147	164	2,529	16
North of Deer Lodge[6]	176	5.0	1,630	NA	NA	40
Deer Lodge to Drummond[3]	610	8.4	1,090	398	1,120	9
Drummond to Milltown[3]	116	10	783	87	2,660	9

1 Nimick, 1990.
2 Brooks, 1988.
3 Moore, 1985.
4 CH_2M Hill *et. al.*, 1991.
5 Axtmann and Luoma, 1991.
6 Rice and Ray, 1984.

2.3.5 Discharges from the Anaconda Smelter

Emissions from the Anaconda Smelter stack have contaminated a large area surrounding Anaconda with the hazardous substances arsenic, cadmium, copper, lead, and zinc. There is evidence that metals from soils contaminated by stack emissions are transported to the Clark Fork River by Mill Creek and Willow Creek via the Mill-Willow Bypass. ESE Inc. (1992) concluded that metals loadings in Mill Creek may originate from soils contaminated by stack emissions or by runoff from Smelter Hill. Exceedences of aquatic life criteria in Willow Creek (cadmium, copper, and lead) and Mill Creek (cadmium and lead) were documented during high-flow sampling in May 1991 (ESE, Inc., 1991). Tetra Tech (1987) concluded that declining water quality in Mill Creek, which flows less than one mile from Smelter Hill, was likely caused by runoff from contaminated soils.

2.3.6 Pathways of Hazardous Substances from Sources to the Clark Fork River

The principal pathways by which hazardous substances enter the Clark Fork River are surface water and sediment pathways. The downstream transport of hazardous substances via the Warm Springs Pond 2 discharge have constituted a historic and ongoing release of hazardous substances to the Clark Fork River. As shown in Section 2.3.1, these discharges have constituted a historic and ongoing release of hazardous substances into the Clark Fork River. Surface water pathways also transport hazardous substances into the Clark Fork River via Warm Springs Creek (Section 2.3.2), and the Opportunity Ponds discharges (Section 2.3.3).

Surface runoff of hazardous substances from riverside tailings deposits has also constituted an historic and ongoing release. For example, simulated storm runoff at the Mill-Willow Bypass was found to contain 640,000 ppb of dissolved copper (see Section 2.3.4). Finally, both contaminated riverside tailings and contaminated riverbed sediments (see Chapter 3.0) act as exposure pathways to the Clark Fork River via direct contact.

2.4 SUMMARY

In summary, numerous sources release hazardous substances into the aquatic ecosystem of Silver Bow Creek and the Clark Fork River. These releases from mining and mineral processing in Butte and Anaconda have been continuous and ongoing since the onset of large-scale copper mining and mineral processing in Butte in approximately 1882.

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3.0 SEDIMENTS

3.1 INTRODUCTION

This chapter, together with the Sediments Report prepared as part of the Assessment (Essig and Moore, 1992), demonstrates that concentrations of hazardous substances in streambed sediments in Silver Bow Creek, the Clark Fork River, and the Warm Springs Ponds greatly exceed baseline concentrations. These contaminated streambed sediments, in turn, serve as a principal exposure pathway to surface water, aquatic benthic macroinvertebrates, and fish. This chapter is organized as follows: Section 3.2 provides a brief overview and description of exposed areas. Section 3.3 provides comparisons of concentrations of hazardous substances in Silver Bow Creek and the Clark Fork River with baseline conditions. Section 3.4 compares the relative contributions of hazardous substances from tributaries to the Clark Fork River to those from Silver Bow Creek. Section 3.5 provides comparisons of concentrations of hazardous substances in Silver Bow Creek and Clark Fork River and corresponding control sites used in the fish population studies (see Chapter 6.0). Finally, Section 3.6 identifies pathways of hazardous substances to Silver Bow Creek and the Clark Fork River.

3.2 DESCRIPTION OF EXPOSED AREAS

3.2.1 Silver Bow Creek

From its origin in Butte, Silver Bow Creek flows west and north and discharges to Warm Springs Ponds, a distance of approximately 40 kilometers (24 miles) (Canonie, 1992). Its average gradient is approximately 0.5%, and its average width is approximately 4.7 meters (15.4 ft) (Chadwick *et al.*, 1986).

The Berkeley Pit, Yankee Doodle Tailings Pond, and associated mining facilities have obliterated much of the original Silver Bow Creek channel (MultiTech, 1987a). The channel from the Weed Concentrator in Butte to Blacktail Creek was reconfigured as the Metro Storm Drain (MSD) in the early 1930s by realigning and filling in the original Silver Bow Creek channel (MultiTech, 1987a). Today, the MSD carries little or no flow, except during storm events or snowmelt runoff (MultiTech, 1987a). The majority of headwater flow in Silver Bow Creek now originates as inflow from Blacktail Creek (Canonie, 1991).

The only perennial "tributaries" to Silver Bow Creek are the Butte Metro Wastewater Treatment Plant (WWTP) discharge, Browns Gulch, German Gulch, and the Silver Lake pipeline discharge near Ramsay. Ephemeral tributaries include Missoula Gulch, Whiskey Gulch, Gimlet Gulch, and Sand Creek (MultiTech, 1987a).

Groundwater contributes a significant portion of the flow to Silver Bow Creek in the Butte area (Canonie, 1992).

3.2.2 Warm Springs Ponds

Warm Springs Ponds are settling and treatment ponds that were constructed near the confluence of Silver Bow Creek and Warm Springs Creek to collect tailings and other mine wastes being carried downstream by Silver Bow Creek (U.S. EPA, 1990). Ponds 1 and 2 were constructed prior to 1920 by the Anaconda Copper Company (MDHES and CH_2M Hill, 1989). Pond 3 was constructed between 1954 and 1959 (MDHES and CH_2M Hill, 1989). Currently, Silver Bow Creek enters Pond 3 from the south, and water is routed from Pond 3 into Pond 2 by two decant towers and into nearby wildlife ponds via siphons (MultiTech, 1987a). The discharge from Pond 2 joins with the Mill-Willow Bypass, which routes the combined flows of Mill and Willow Creeks around the pond system. Pond 1 is no longer used. The Clark Fork River begins at the confluence of Warm Springs Creek and the combined Mill-Willow Bypass and Pond 2 discharge about one mile below Warm Springs Ponds (Figure 3-1).

Lime (calcium carbonate) has been added to pond inflows since 1959 on a seasonal or streamflow basis to aid in precipitating dissolved metals (Johnson and Schmidt, 1988). Exposed tailings and sediments cover an area of approximately 257 hectares (634 acres) and vary in thickness from less than three centimeters (1 inch) to over one meter (3 feet) (U.S. EPA, 1990). Submerged sediments cover an area of approximately 500 hectares (1,235 acres) and range in thickness from less than one meter (3 feet) to over 6 meters (18 feet) (U.S. EPA, 1990). Collectively, the ponds contain an estimated 15 million cubic meters (19 million cubic yards) of tailings and sediments contaminated with arsenic, cadmium, copper, lead, zinc, and other heavy metals (Hydrometrics, 1983; MultiTech, 1987b). These tailings and sediments are typically fine to coarse-grained sand (U.S. EPA, 1990).

3.2.3 Clark Fork River

The headwaters of the Clark Fork River are formed by the confluence of Warm Springs Creek with the combined Mill-Willow Bypass and Pond 2 discharge channel (Figure 3-1). From this confluence to the Milltown Reservoir, a distance of approximately 195 kilometers (120 miles), the Clark Fork River is relatively shallow with an overall gradient of approximately 0.25% (Brook and Moore, 1988; Essig and Moore, 1992). Major tributaries in this reach include Little Blackfoot River, Flint Creek, and Rock Creek (see Figure 1-1)

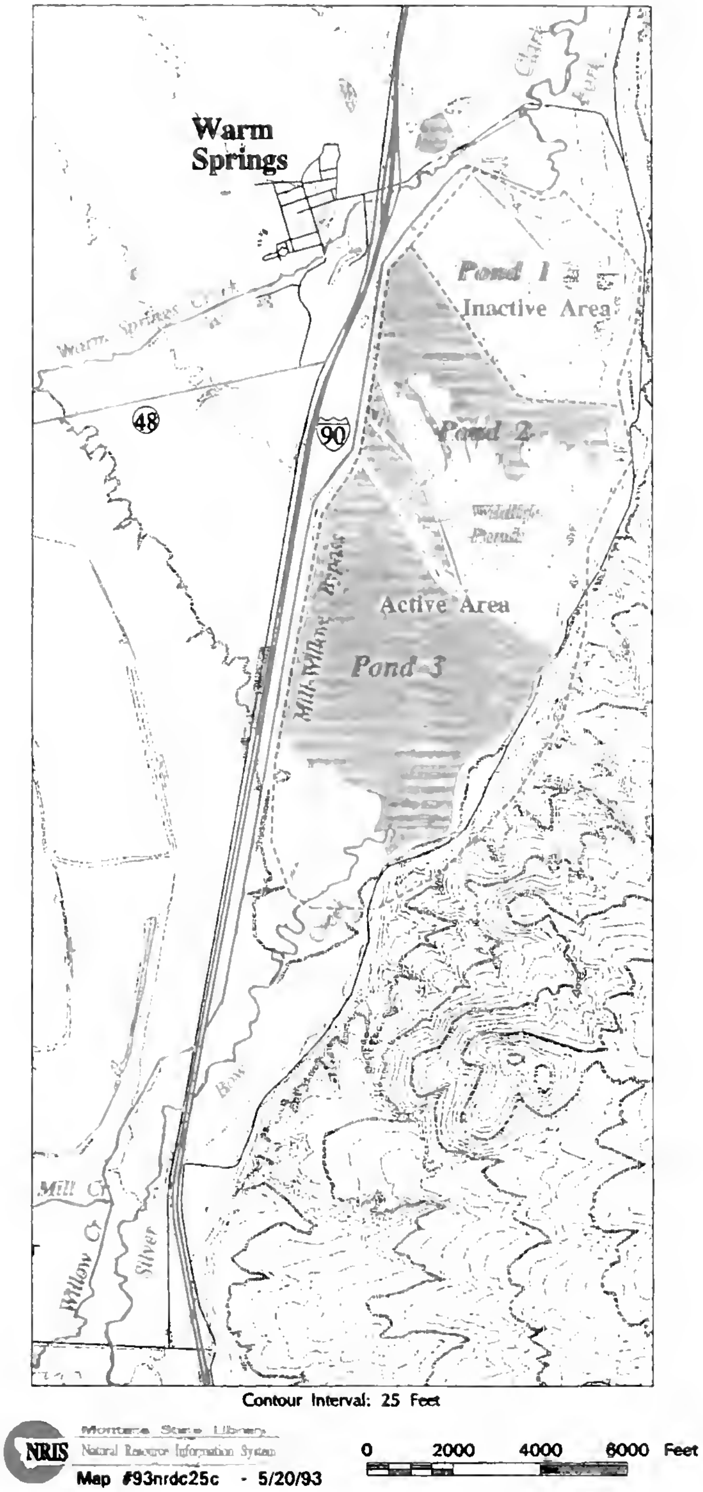

Figure 3-1. Warm Springs Ponds Area.

Streamflow in the Clark Fork River increases downstream and varies seasonally. For the years 1985-1990, monthly mean streamflow ranged from approximately 30 cubic feet per second (cfs) in August to 191 cfs in May near Galen (approximately 8 kilometers (5 miles) from the headwaters just below the Warm Springs Ponds) and from 544 cfs in August to 2,200 cfs in May at Turah Bridge, a short distance upstream of Milltown (Lambing, 1991).

The Clark Fork River is a high-gradient system that carries large amounts of coarse sand during spring runoff and other high flows (Brook and Moore, 1988). Metals-laden tailings, deposited along floodplains over the last 100 years, contribute to this coarse fraction carried by the river (Brook and Moore, 1988; Johnson and Schmidt, 1988). The size, concentration, and loadings of suspended sediments depend on streamflow characteristics. Suspended sediment concentration, grain size, and loadings tend to increase as flow rates increase in the Clark Fork River, since higher energy waterflow can carry larger particles (ENSR, 1992; Lambing, 1991).

The bed sediments of the Clark Fork River are composed of particles of varying grain-sizes, from fine-grained to coarse-grained particles (Brook and Moore, 1988). Of these fractions, the fine-grained portion of bed sediment ($< 63\ \mu m$) is particularly important in determining sediment contamination from anthropogenic sources and in assessing sediment impacts to biota, as described below.

Fine-grained sediments represent sediment recently suspended in the river and carried downstream, and thus provide a strong basis for establishing anthropogenic contaminant sources (Essig and Moore, 1992). Fine-grained sediment analysis also provides a more reliable and less biased means of assessing sediment contamination than does bulk sediment analysis (Axtmann and Luoma, 1991). Finally, benthic macroinvertebrates are directly exposed to and can uptake contaminants from fine-grained sediments in depositional zones and micro-depositional habitats in a riverine environment such as the Clark Fork River (Essig and Moore, 1992; Luoma, 1992). The correlation of metals concentrations in macroinvertebrates with concentrations in fine-grained sediments from the Clark Fork River (see Chapter 5.0) also demonstrates the importance of fine-grained sediments to benthic macroinvertebrates (Axtmann and Luoma, 1991; Cain *et al.*, 1992).

3.3 EXTENT OF SEDIMENT CONTAMINATION

3.3.1 Sediment Contamination in Silver Bow Creek

As a result of hazardous substance releases to Silver Bow Creek, sediments throughout the creek are contaminated with hazardous substances relative to baseline conditions.

Historical data to assess the baseline condition of Silver Bow Creek prior to hazardous substance releases are not available, because releases to Silver Bow Creek have occurred since the late 1800s. Therefore, streams in or near the Clark Fork River Basin that are comparable to Silver Bow Creek except for exposure to the hazardous substance releases were selected as control areas to represent baseline conditions. Control areas against which Silver Bow Creek bed sediment metals concentrations were compared include Gold Creek, Ruby River, and Rock Creek (Essig and Moore, 1992). Gold Creek and Rock Creek are tributaries to the Clark Fork River downstream of Silver Bow Creek, and the Ruby River is located in a nearby drainage basin. All three control stream drainages are relatively unaffected by mining activities.

Mean concentrations of arsenic, cadmium, copper, lead, and zinc in Silver Bow Creek fine sediments (<63μm) are compared to baseline conditions in Table 3-1. Figures 3-2 through 3-6 plot concentrations of hazardous substances as a function of downstream distance in Silver Bow Creek and the Clark Fork River relative to baseline conditions. Mean copper sediment concentrations in Silver Bow Creek are approximately 500 times greater than baseline concentrations (Essig and Moore, 1992). Mean concentrations of cadmium and zinc are more than 150 times greater than baseline, and arsenic and lead are approximately 90 and 100 times greater than baseline, respectively (Essig and Moore, 1992).

Table 3-1
Mean Concentrations of Hazardous Substances in Fine Bed Sediments
(units in ppm dry weight)

	No. of Sites	Arsenic	Cadmium	Copper	Lead	Zinc
Silver Bow Creek	13	605	34.0	9,170	1,510	8,800
Baseline (Rock Creek, Gold Creek, Ruby River)	19	7.0	0.22	20	15.4	56.5

Source: Essig and Moore, 1992.

3.3.2 Sediment Contamination in Warm Springs Ponds

In the approximately 80 years since the first pond was constructed, an estimated 15 million cubic meters (19 million cubic yards) of mill tailings, mine waste rock, natural

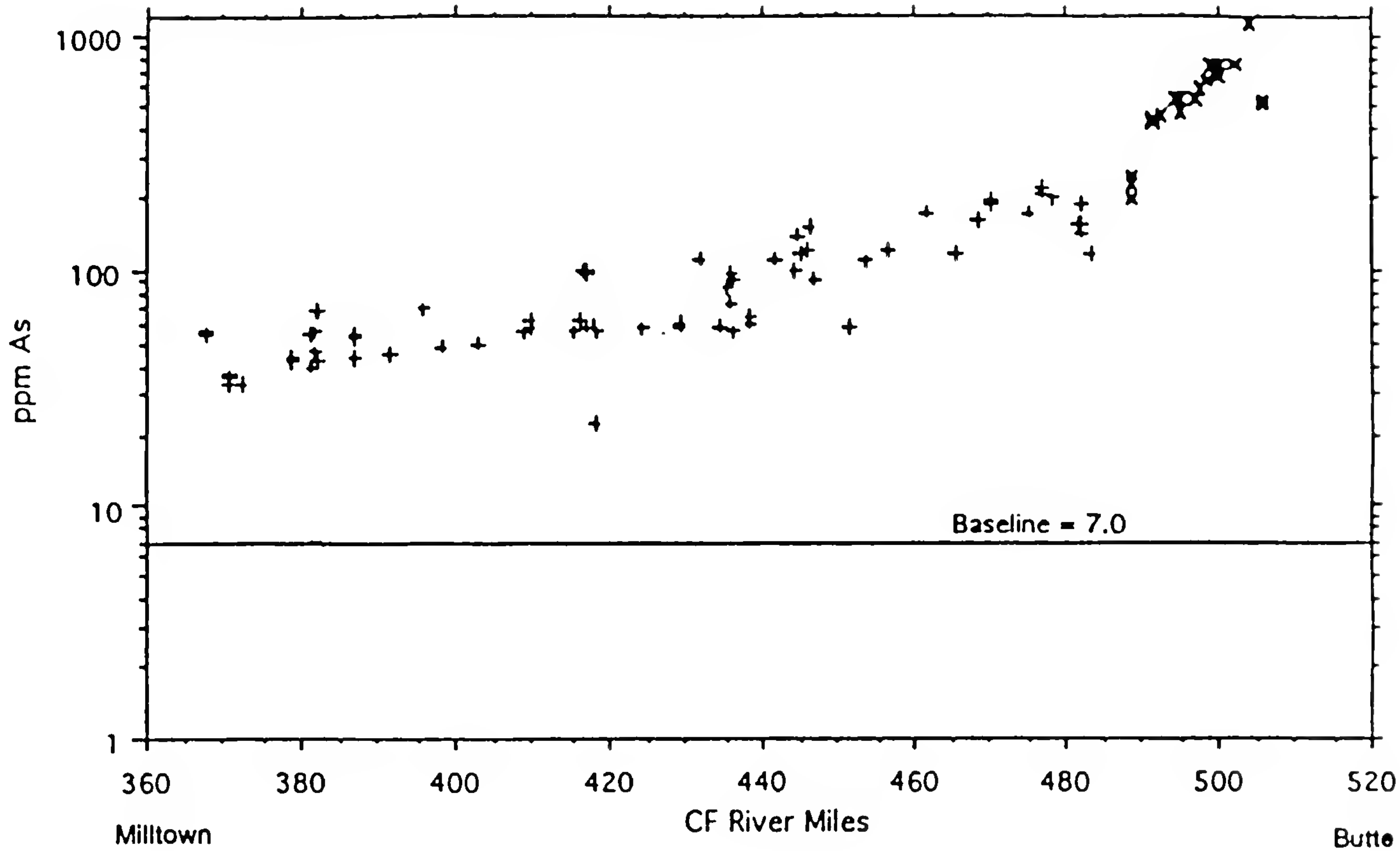

Figure 3-2. Sediment Arsenic Trend. Source: Essig and Moore, 1992.
(+ = Clark Fork River; × = Silver Bow Creek)

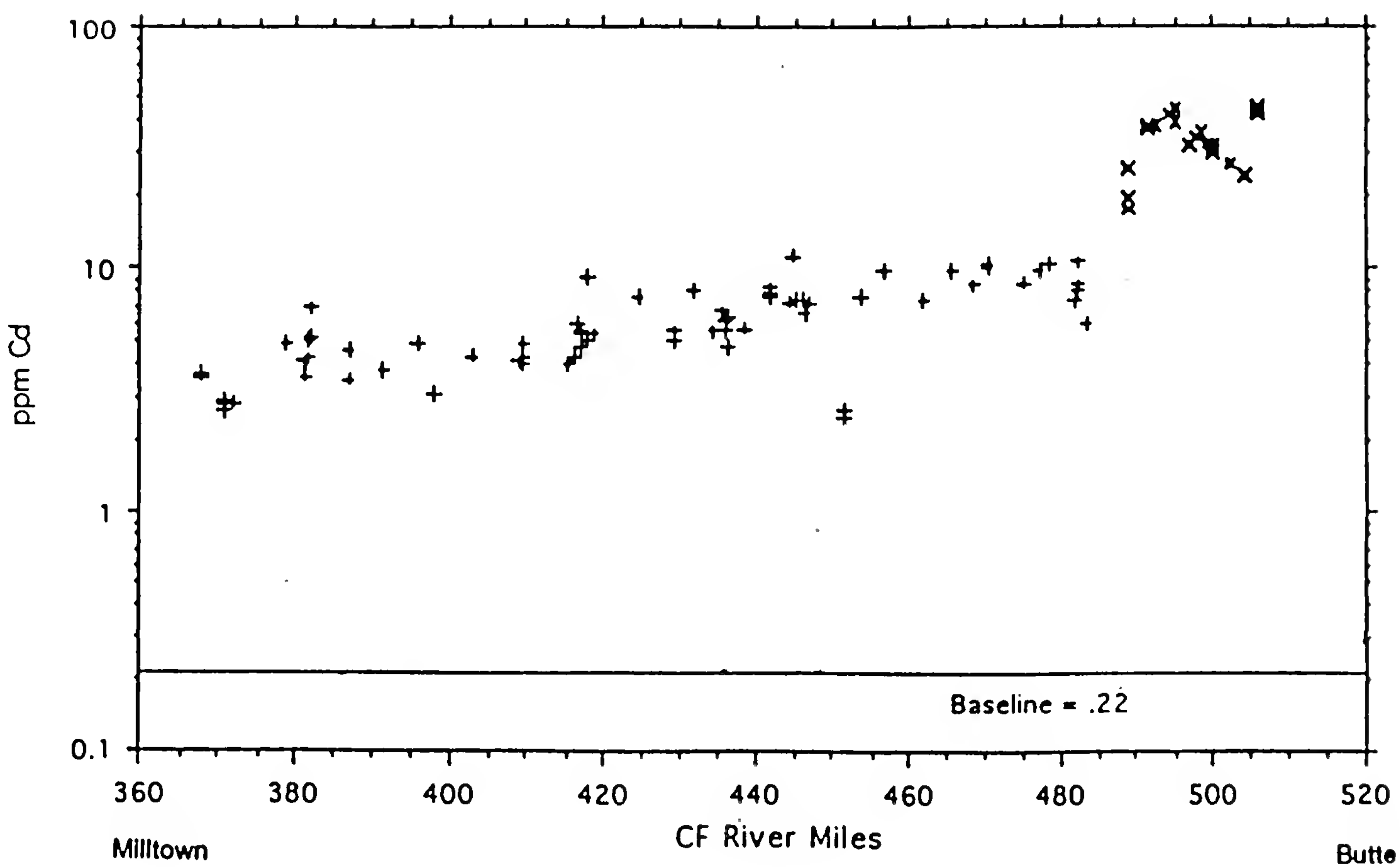

Figure 3-3. **Sediment Cadmium Trend.** Source: Essig and Moore, 1992.
(+ = Clark Fork River; × = Silver Bow Creek)

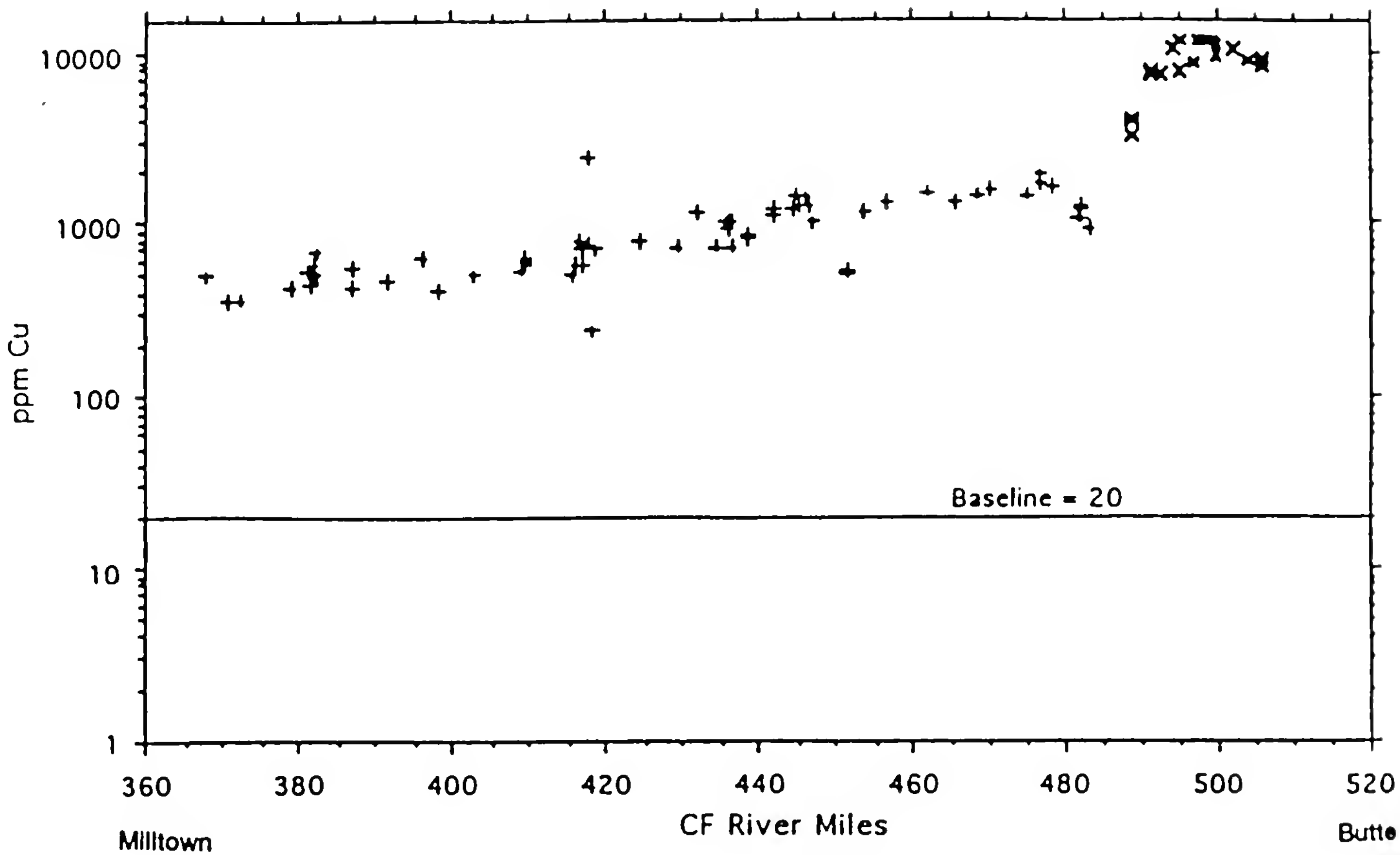

Figure 3-4. Sediment Copper Trend. Source: Essig and Moore, 1992.
(+ = Clark Fork River; x = Silver Bow Creek)

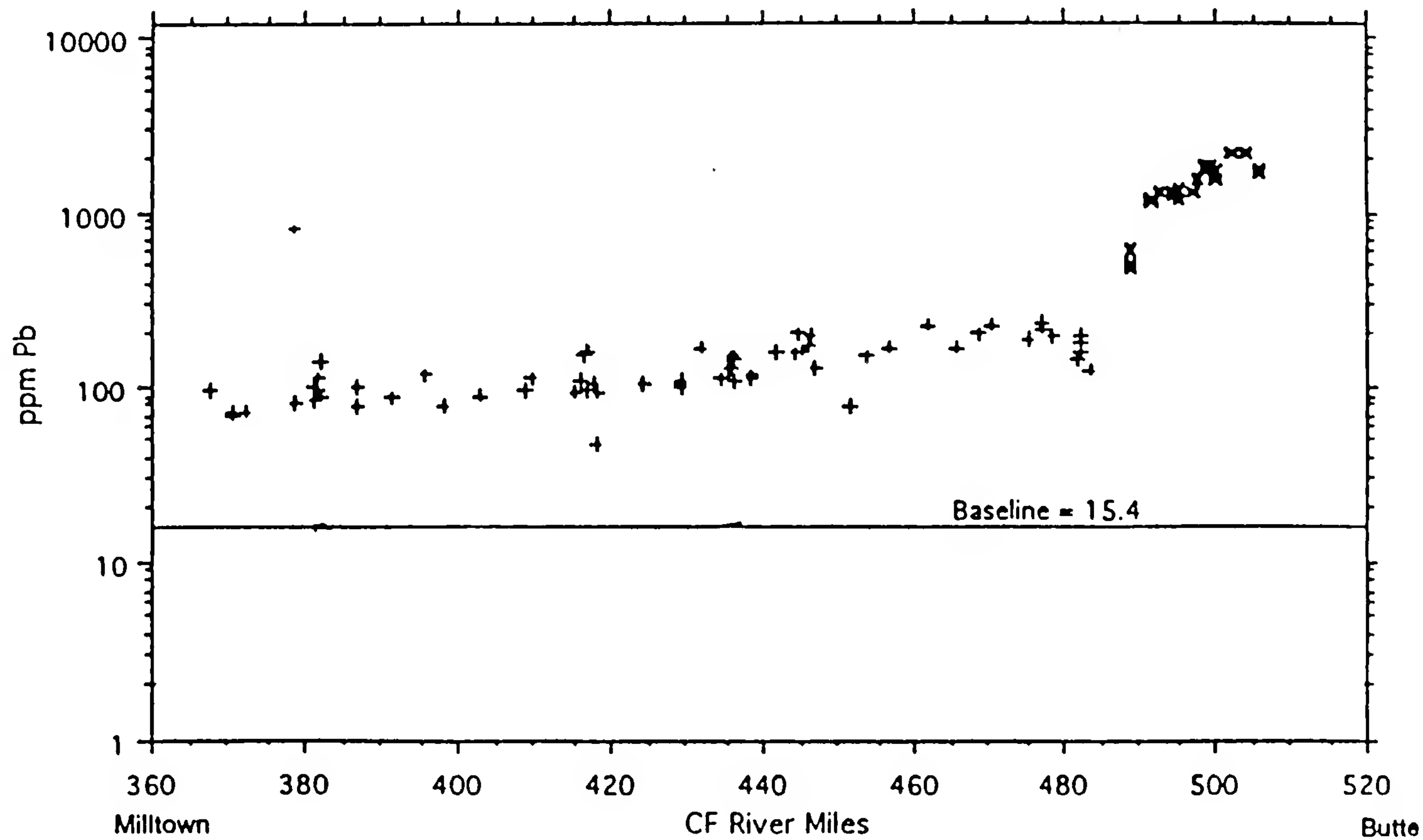

Figure 3-5. Sediment Lead Trend. Source: Essig and Moore, 1992.
(+ = Clark Fork River; x = Silver Bow Creek)

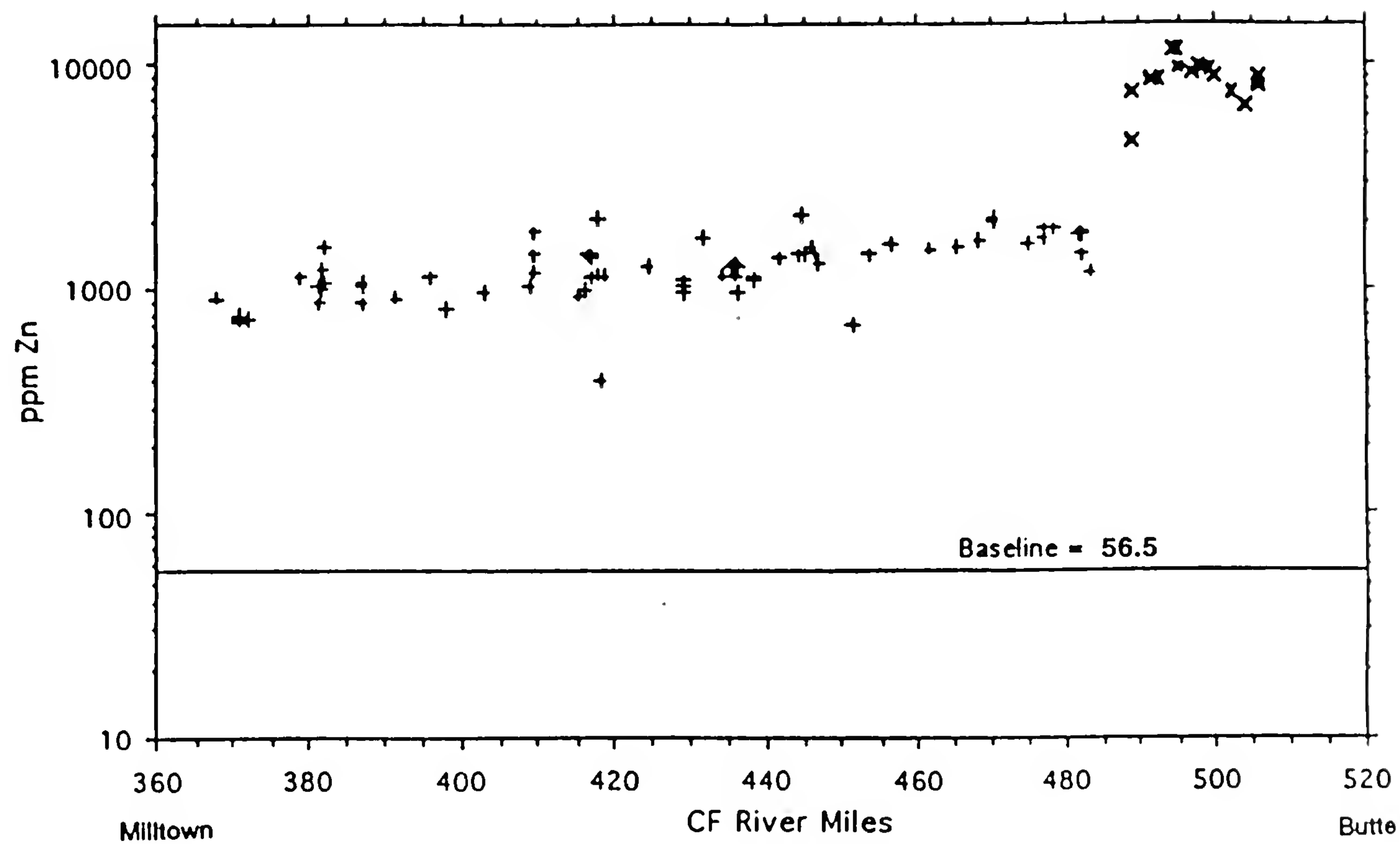

Figure 3-6. **Sediment Zinc Trend.** Source: Essig and Moore, 1992.
(+ = Clark Fork River; x = Silver Bow Creek)

sediments, and precipitates have collected in the ponds (Hydrometrics, 1983). Table 3-2 presents mean arsenic and metals concentrations in bed sediments of the three ponds, along with baseline concentrations. Mean arsenic concentrations in the ponds exceed baseline conditions by roughly 40-80 times, copper concentrations exceed baseline by roughly 150-350 times, cadmium concentrations exceed baseline by roughly 45-850 times, and lead and zinc concentrations exceed baseline by roughly 15-45 and 40-300 times, respectively. These contaminated pond sediments can be remobilized and serve as an ongoing source of hazardous substances to surface water and groundwater.

Table 3-2
Mean Concentrations of Hazardous Substances in Warm Springs Ponds Bed Sediments (metals in ppm dry weight)

	Arsenic	Cadmium	Copper	Lead	Zinc
Pond 1[1]	408	10	2,886	670	2,212
Pond 2[2]	590	36	4,661	726	4,859
Pond 3[2]	301	195	7,015	252	17,318
Baseline[3]	7.0	0.22	20	15.4	56.5

1 U.S. EPA, 1992.
2 CH_2M Hill, 1988 as cited in Johnson and Schmidt, 1988.
3 Essig and Moore, 1992.

3.3.3 Sediment Contamination in the Clark Fork River

As a result of hazardous substance releases to and transport within the Clark Fork River, sediments throughout the river from its headwaters to at least as far downstream as Milltown, including the Milltown Reservoir, are contaminated with hazardous substances at concentrations well above baseline.

As with Silver Bow Creek, no historical data are available to characterize pre-release conditions in the Clark Fork River. Baseline conditions were determined using the control areas described previously (Gold Creek, Ruby River, and Rock Creek).

As with Silver Bow Creek, concentrations of arsenic, cadmium, copper, lead, and zinc exceed baseline concentrations by orders-of-magnitude (Figures 3-2 through 3-6).

Overall, a clear pattern of decreasing concentration with downstream distance from upstream sources in Butte is apparent.

Table 3-3 compares fine-grained sediment concentrations of arsenic, cadmium, copper, lead, and zinc in the Clark Fork River with fine-grained sediment concentrations in control streams; Figures 3-7 to 3-11 plot these concentrations for each of the hazardous substances for three Clark Fork River reaches: Clark Fork River - Upper (headwaters to Garrison Junction); Clark Fork River - Middle (Garrison to Rattler Gulch (near Bradman)); and Clark Fork River - Lower (Rattler Gulch to Milltown Reservoir). Median copper concentrations in the lower, middle, and upper reaches of the Clark Fork River are 25, 39, and 65 times greater than baseline concentrations, respectively. Median cadmium concentrations are 19, 25, and approximately 35 times greater than baseline in these reaches, whereas zinc concentrations are 18, 21, and 27 times greater than baseline. Median arsenic concentrations are 7, 9, and 20 times greater than baseline in the lower, middle, and upper reaches, respectively; lead concentrations are 6, 8, and 11 times greater than baseline in these reaches.

Table 3-3
Concentrations of Hazardous Substances in Fine-grained Bed Sediment
Clark Fork River (CFR) and Control Streams
(units in ppm dry weight)

	No. of Sites	Arsenic	Cadmium	Copper	Lead	Zinc
CFR — upper[1]	19	142	7.7	1,302	176	1,573
CFR — middle[1]	19	63.2	5.5	785	116	1,173
CFR — lower[1]	17	50.3	4.3	502	93	1,020
Baseline[2]	19	7.0	0.22	20	15.4	56.5

1 Values are data medians.
2 Values are data means.
Source: Essig and Moore, 1992.

In conclusion, these data show that bed sediment concentrations of arsenic, cadmium, copper, lead, and zinc are elevated above baseline conditions throughout Silver Bow Creek and the Clark Fork River. Essig and Moore (1992) contains a more detailed statistical characterization of this contamination.

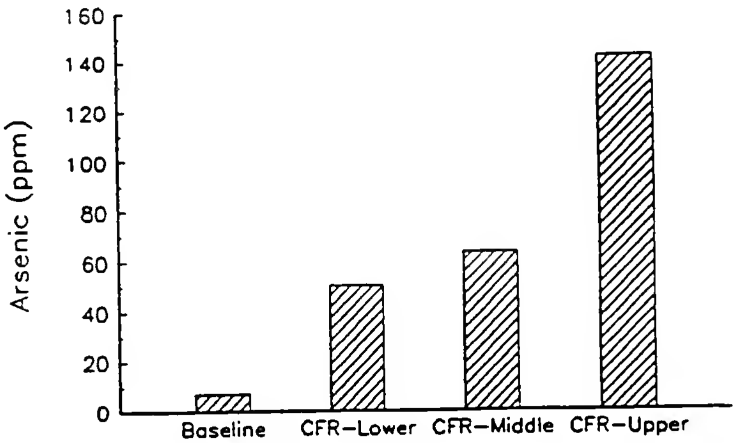

Figure 3-7. **Sediment Arsenic Concentrations in the Clark Fork River and Control Streams.** Baseline values are means, CFR values are medians. Source: Essig and Moore, 1992.

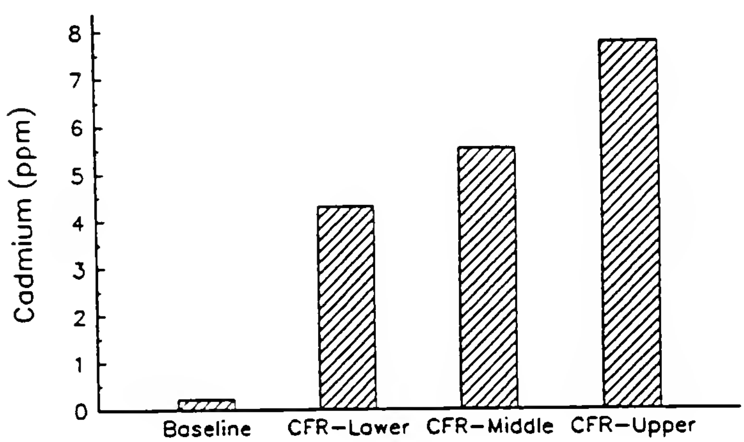

Figure 3-8. **Sediment Cadmium Concentrations in the Clark Fork River and Control Streams.** Baseline values are means, CFR values are medians. Source: Essig and Moore, 1992.

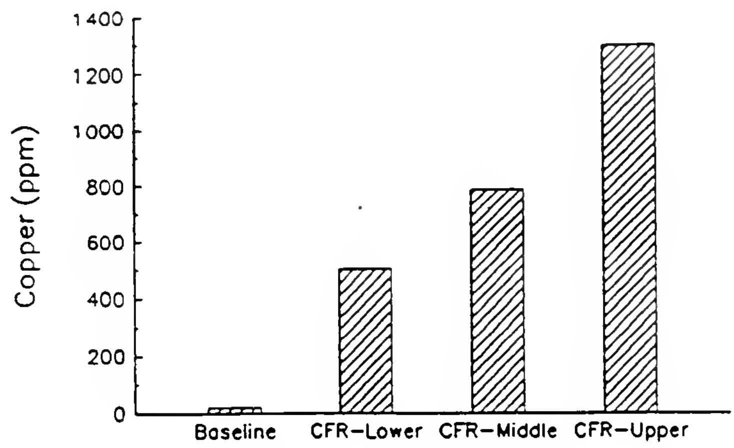

Figure 3-9. Sediment Copper Concentrations in the Clark Fork River and Control Streams. Baseline values are means, CFR values are medians. Source: Essig and Moore, 1992.

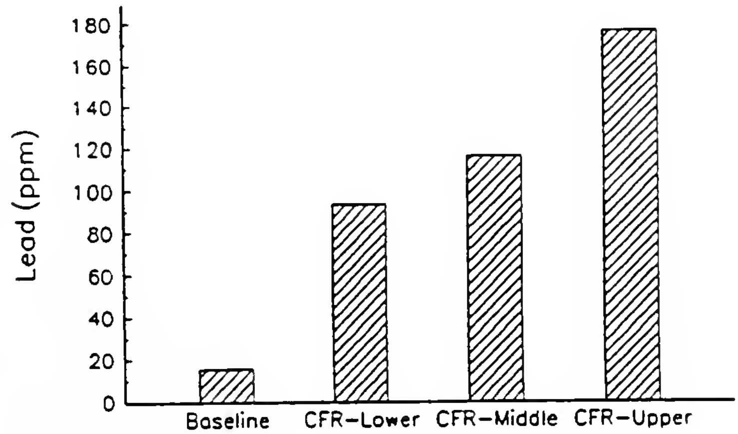

Figure 3-10. Sediment Lead Concentrations in the Clark Fork River and Control Streams. Baseline values are means, CFR values are medians. Source: Essig and Moore, 1992.

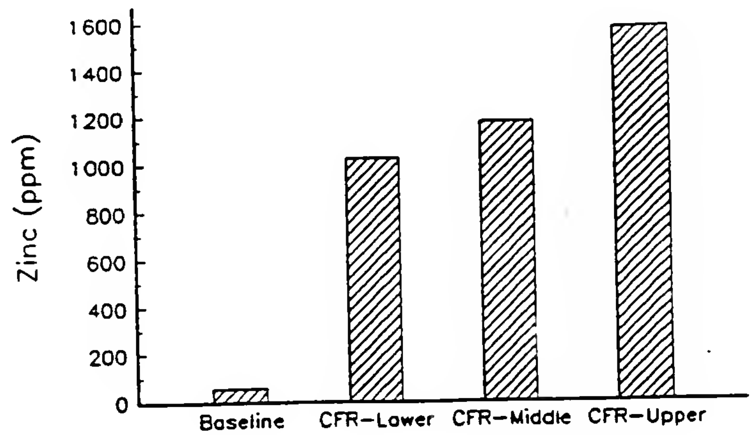

Figure 3-11. Sediment Zinc Concentrations in the Clark Fork River and Control Streams. Baseline values are means, CFR values are medians. Source: Essig and Moore, 1992.

3.4 LARGE-SCALE MINING AND MINERAL PROCESSING OPERATIONS IN BUTTE AND ANACONDA AS SOURCES OF SEDIMENT CONTAMINATION

The hazardous substances in the bed sediments of Silver Bow Creek, Warm Springs Ponds, and the Clark Fork River originated from large-scale mining and mineral processing operations in the Butte and Anaconda areas.

Three primary factors establish that Silver Bow Creek, Warm Springs Ponds, and the Clark Fork River have been contaminated by large-scale mining operations in Butte and Anaconda: (1) the downstream decline in hazardous substance concentrations is indicative of an upstream source in Butte and Anaconda; (2) mining and mineral processing operations in Butte and Anaconda are known sources of hazardous substance releases; and (3) significant downstream transport of hazardous substances from sources has been documented. This section describes these factors in greater detail.

1. **The distribution of hazardous substances in bed sediments of the Clark Fork River from Warm Springs Ponds to the Milltown Reservoir exhibits a logarithmic decline in concentrations with downstream distance. Such a pattern is indicative of bed sediment contamination resulting from an**

upstream source — historic and ongoing releases from Silver Bow Creek, the Warm Springs Ponds, and Warm Springs Creek.

Concentrations of hazardous substances in bed sediments of the Clark Fork River are highest at its origin and generally decrease downstream. Figures 3-2 through 3-6, taken from Essig and Moore (1992), plot fine bed sediment (< 63 μm) concentrations versus river mile for arsenic, cadmium, copper, lead, and zinc. The downstream trend of these hazardous substances follows a log-linear progression at least as far as the Milltown Reservoir. Other investigations have also documented this log-linear relationship in the Clark Fork River between Warm Springs Ponds and Milltown (Axtmann *et al.*, 1990; Axtmann and Luoma, 1991; Moore, 1985). Such a log-linear decline of hazardous substances with river mile is indicative of releases from an upstream source being diluted by cleaner sediment input downstream of the source (Essig and Moore, 1992; Axtmann *et al.*, 1990; Axtmann and Luoma, 1991; Lambing, 1991; Moore, 1985). In the case of the Clark Fork River, the upstream sources consist of the historic and ongoing releases from sources in the Butte and Anaconda areas, as described in Chapter 2.0

2. **Hazardous substances corresponding to those found in bed sediments of the Clark Fork River are known to have been released in large quantities to the Clark Fork River from mining and mineral processing operations in Butte and Anaconda. No other significant sources of these hazardous substances are known to occur along the Clark Fork River, including sediment input from its tributaries.**

As described in Chapter 2.0, Butte and Anaconda area mining and mineral processing operations have been and continue to be primary sources of the hazardous substances arsenic, cadmium, copper, lead, and zinc to the Clark Fork River via Silver Bow Creek.

Clark Fork River tributaries below Warm Springs Ponds generally have much lower concentrations of arsenic, cadmium, copper, lead, and zinc in sediments than the Clark Fork River (Essig and Moore, 1992; Axtmann and Luoma, 1991; Moore, 1985). Although mining activity within the drainage basins of these tributaries has caused elevated metals concentrations in some tributary sediments, neither the mining nor the metals contamination approaches the scale of Butte-Anaconda operations and contamination (Essig and Moore, 1992). Of these tributary drainage basins, the Flint Creek basin has been impacted the most by hard rock mining and mineral processing; Flint Creek sediments are elevated above control stream bed sediments in arsenic, cadmium, lead, and zinc (Essig and Moore, 1992). Nevertheless, detailed studies of bed sediment concentrations near the mouth of Flint Creek show that the effects of metals input from Flint Creek to the Clark Fork River are in a short distance overwhelmed by the contamination of Clark Fork River bed sediments from Butte and Anaconda area

sources (Essig and Moore, 1992; Axtmann and Luoma, 1991). Figures 3-12 through 3-19, taken from Essig and Moore (1992), show the pattern of hazardous substances in bed sediments of the Clark Fork River in the immediate vicinities of the tributaries Little Blackfoot River, Gold Creek, Rock Creek, and Flint Creek. The figures show that inputs from tributary streams have little or no measurable impact on hazardous substance concentrations in the Clark Fork River.[1]

Sediment "fingerprinting" studies, in which the ratios of different bed sediment metals concentrations are compared within and between streams, also demonstrate that hazardous substances in bed sediments of the Clark Fork River originate from sources in Butte and Anaconda and not other tributaries. The ratios of sediment metals within any given stream depend on the types of metals sources within that stream and the geochemical processes which may selectively partition elements. Therefore, similar ratios in sediments from different areas implies similar source chemistry. Conversely, different metals ratios generally implies different source chemistry (Essig and Moore, 1992).

In general, the ratios of arsenic, cadmium, copper, lead, and zinc concentrations in bed sediments are relatively constant throughout the Clark Fork River from its headwaters near Warm Springs to Milltown, and Silver Bow Creek is the only tributary with elemental ratios similar to those of the Clark Fork River (Essig and Moore, 1992). This pattern indicates that bed sediments in Silver Bow Creek and in the entire Clark Fork River downstream to Milltown share the same primary source(s) of these hazardous substances, and that no other tributaries contribute any appreciable amount of these hazardous substances to the bed sediments of the Clark Fork River (Essig and Moore, 1992).

3. **Significant downstream transport of hazardous substances has been documented in studies of metal loads in Silver Bow Creek and the Clark Fork River.**

Measurements of hazardous substances associated with suspended sediment in waters of the Clark Fork River and its tributaries demonstrate the high loads of metals carried downstream by the Clark Fork River relative to its tributaries. Suspended sediments in the Clark Fork River contain much higher concentrations of the hazardous substances arsenic, cadmium, copper, lead and zinc than those in tributaries to the Clark Fork River (ENSR, 1992; Lambing, 1991). Table 3-4 presents data on the average annual loadings of these substances in the Clark Fork River and in two major tributarie...

[1] Even Flint Creek, which has had mining activity and contains elevated concentrations of lead and arsenic, does not contribute an observable loading of contaminated sediment to the Clark Fork River. Any inputs from Flint Creek are quickly overwhelmed by the Clark Fork River concentrations.

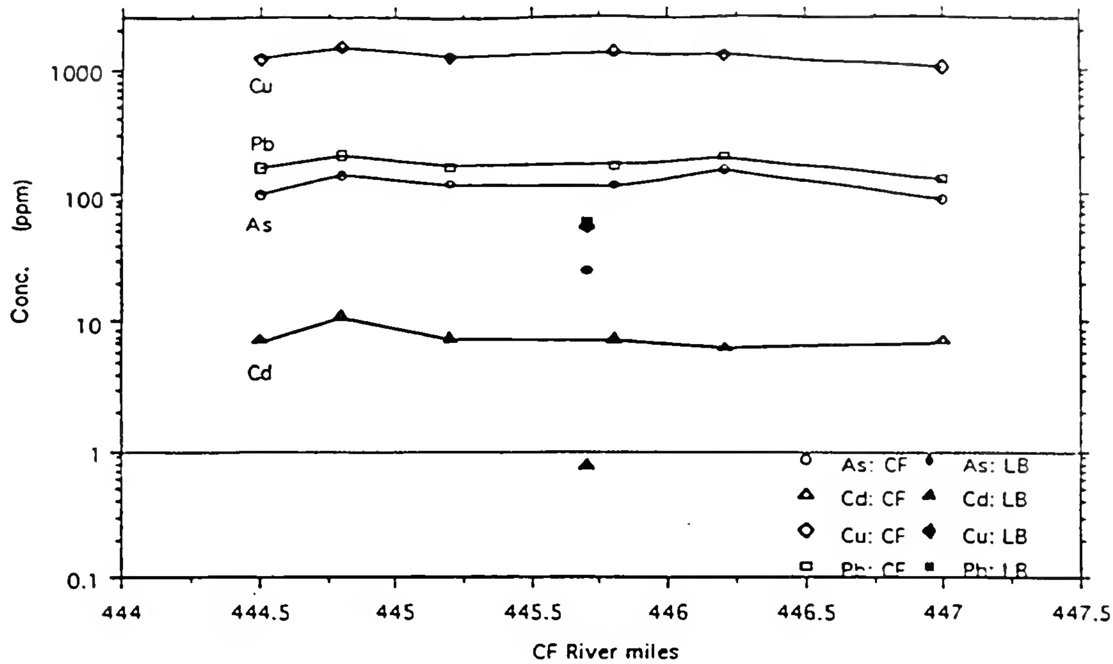

Figure 3-12. Concentrations of Hazardous Substances in Clark Fork River Sediments Near Little Blackfoot River. Source: Essig and Moore, 1992.

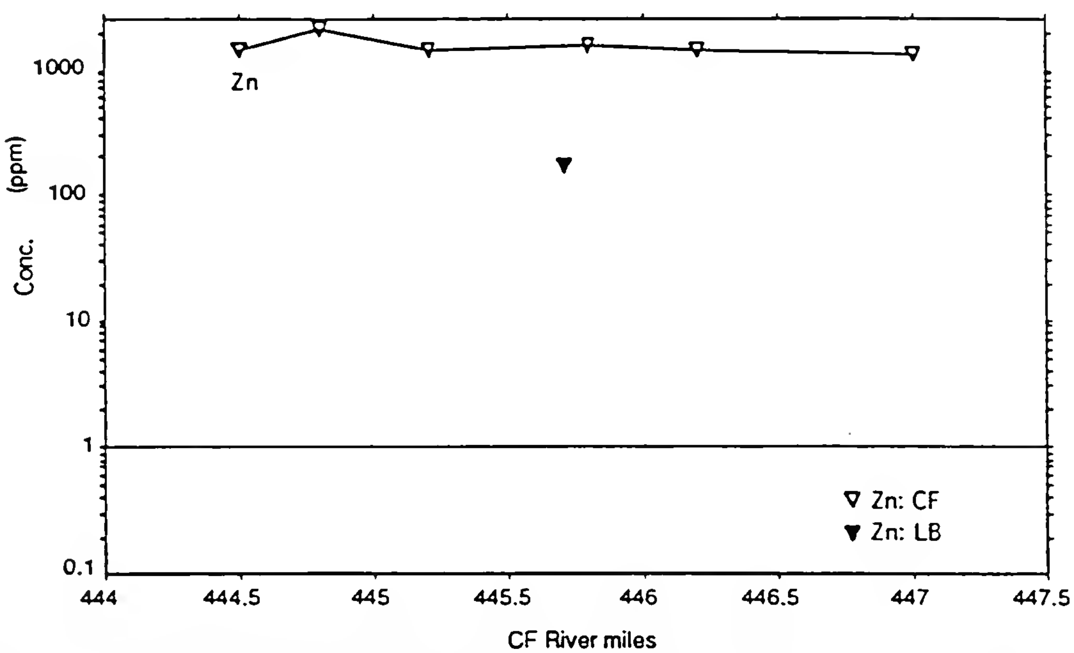

Figure 3-13. Concentrations of Zinc in Clark Fork River Sediments Near Little Blackfoot River. Source: Essig and Moore, 1992.

(CF = Clark Fork River; LB = Little Blackfoot River)

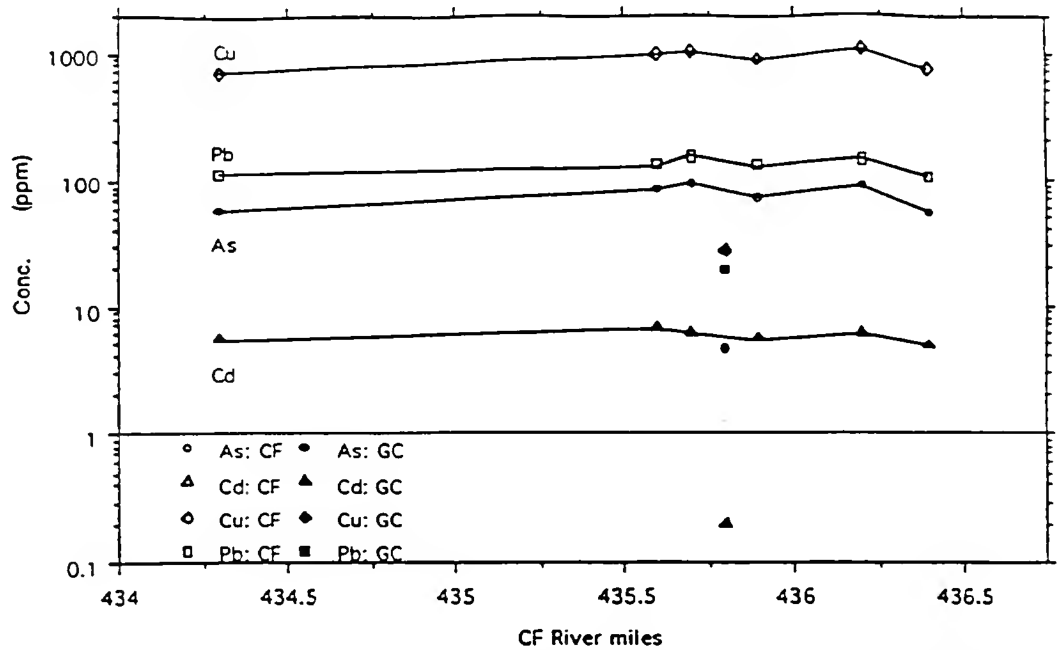

Figure 3-14. Concentrations of Hazardous Substances in Clark Fork River Sediments Near Gold Creek. Source: Essig and Moore, 1992.

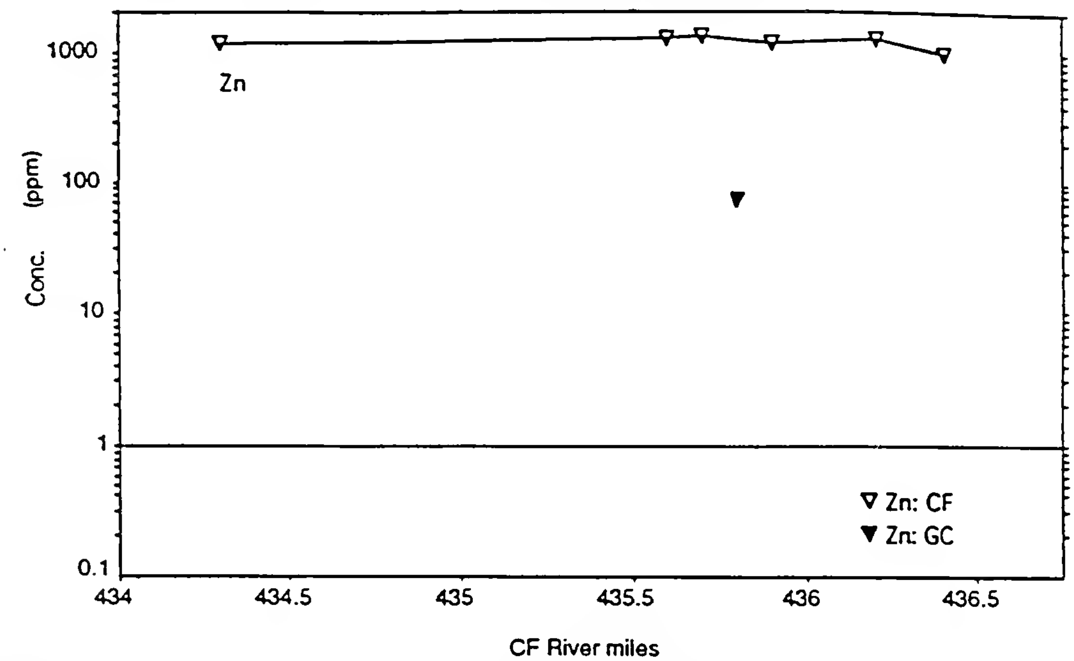

Figure 3-15. Concentrations of Zinc in Clark Fork River Sediments Near Gold Creek. Source: Essig and Moore, 1992.

(CF = Clark Fork River; GC = Gold Creek)

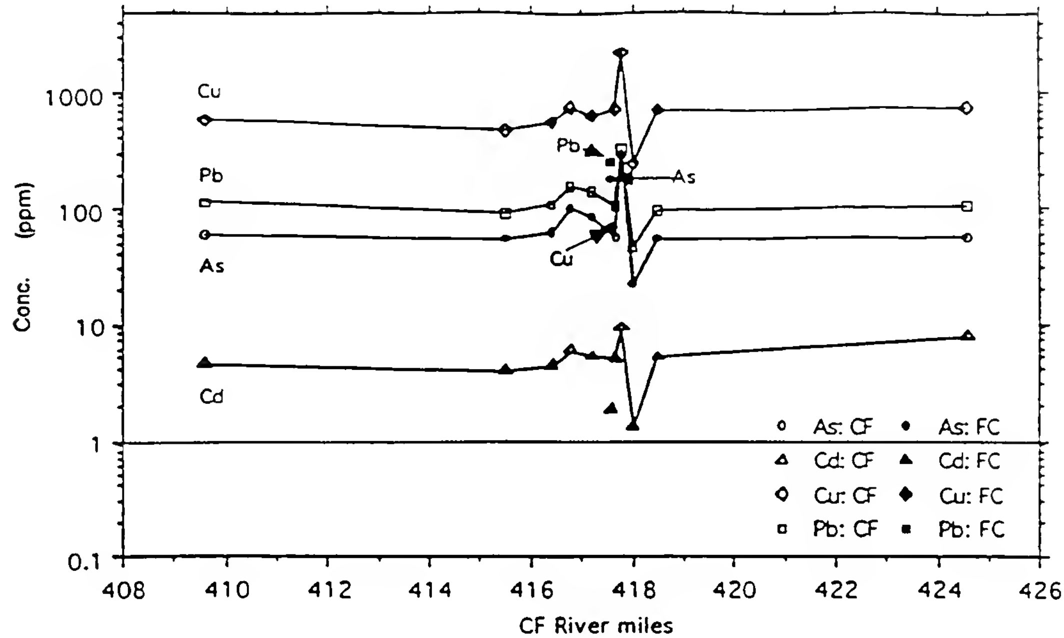

Figure 3-16. Concentrations of Hazardous Substances in Clark Fork River Sediments Near Flint Creek. Source: Essig and Moore, 1992.

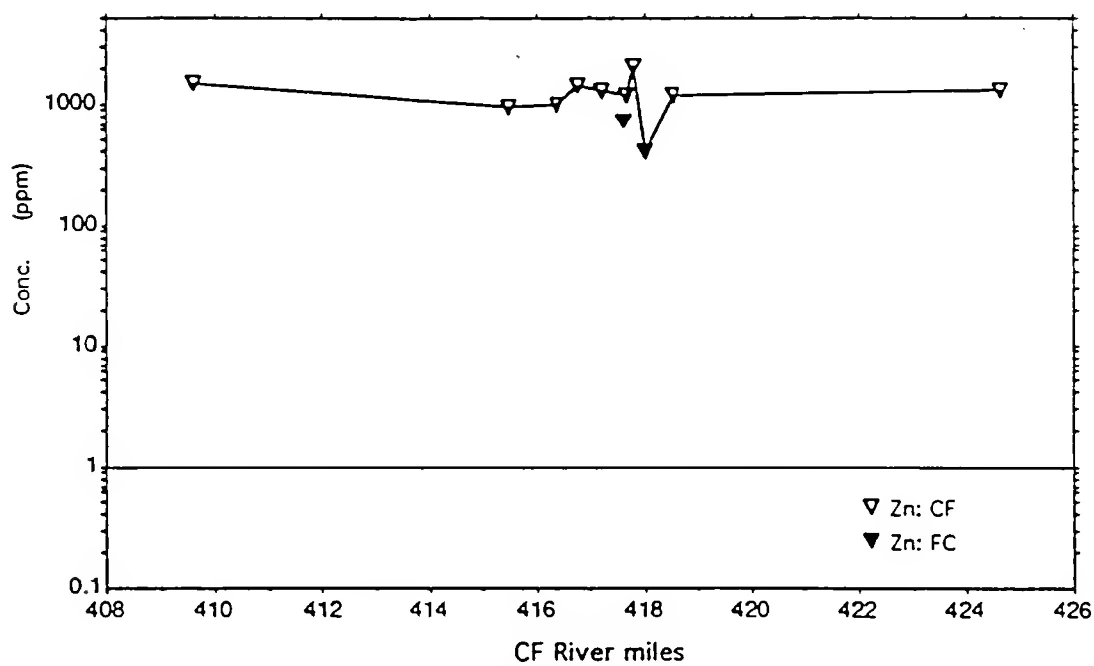

Figure 3-17. Concentrations of Zinc in Clark Fork River Sediments Near Flint Creek. Source: Essig and Moore, 1992.

(CF = Clark Fork River; FC = Flint Creek)

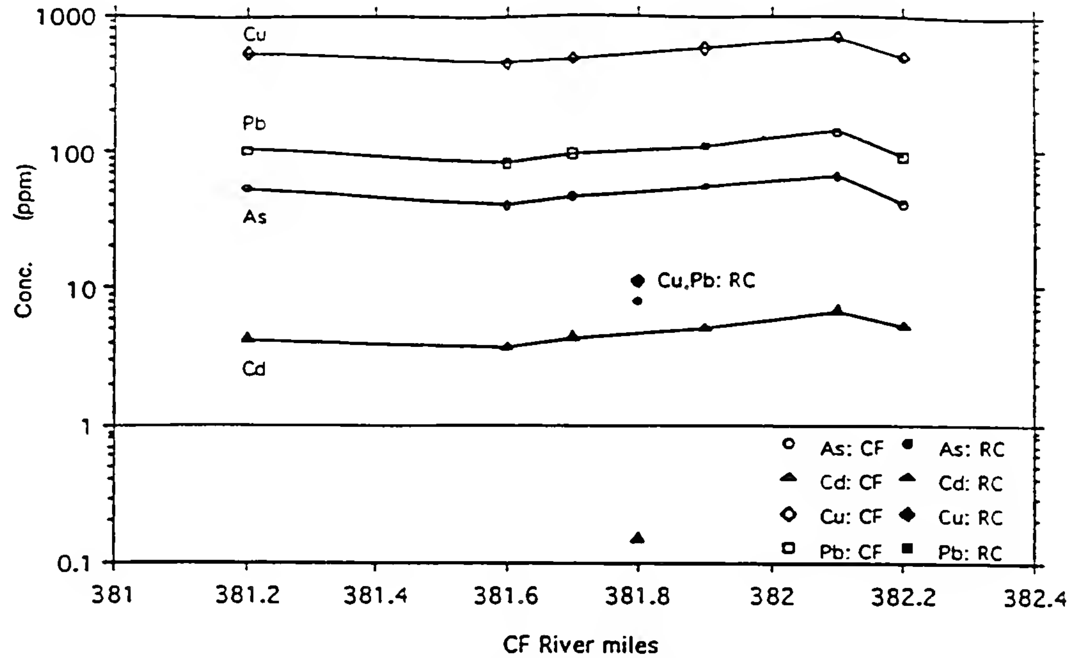

Figure 3-18. Concentrations of Hazardous Substances in Clark Fork River Sediments Near Rock Creek. Source: Essig and Moore, 1992.

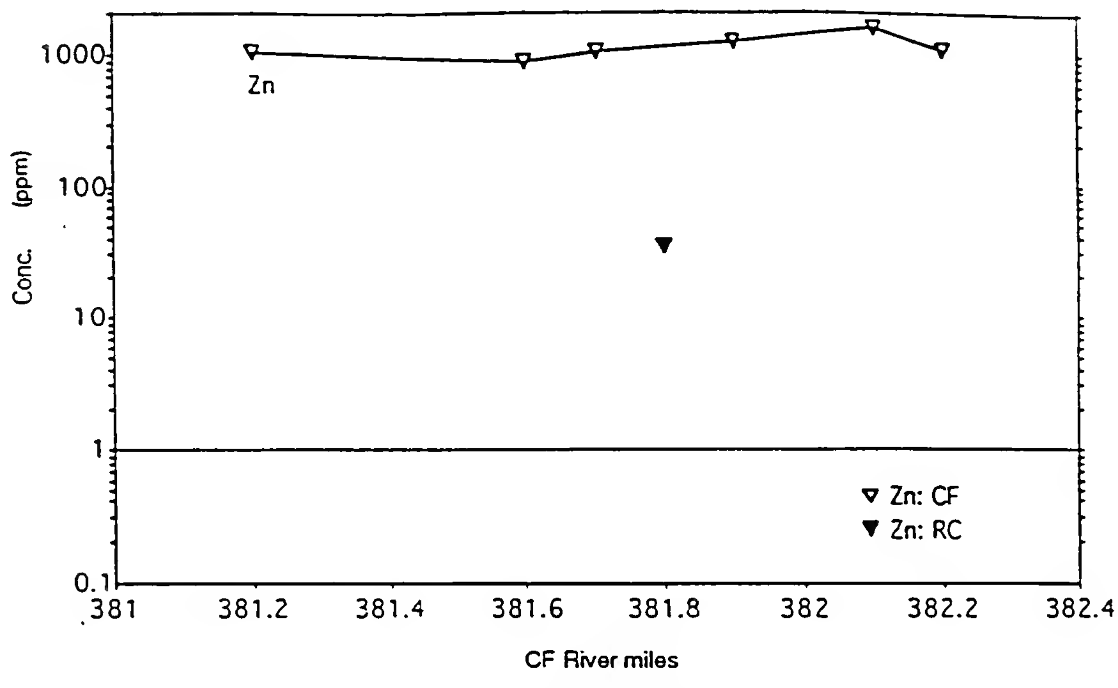

Figure 3-19. Concentrations of Zinc in Clark Fork River Sediments Near Rock Creek. Source: Essig and Moore, 1992.

(CF = Clark Fork River; RC = Rock Creek)

Table 3-4
Median Concentrations and Mean Annual Estimated Loads of Hazardous Substances in Suspended Sediment in the Clark Fork River
1986-1990

Clark Fork River Location:	Arsenic		Copper		Lead		Zinc	
	Conc. in Suspended Sediment (mg/kg)	Annual Load (tons)	Conc. in Suspended Sediment (mg/kg)	Annual Load (tons)	Conc. in Suspended Sediment (mg/kg)	Annual Load (tons)	Conc. in Suspended Sediment (mg/kg)	Annual Load (tons)
CFR at Galen	400	1.6	1,950	4.5	250	0.4	3,800	6.2
CFR at Deer Lodge	140	3.3	1,200	11.7	160	1.4	1,700	16.8
CFR at Turah	50	7.1	550	37.2	125	12.3	1,200	44.4
Rock Creek (control)	10	0.2	200	1.5	50	1.3	850	4.1
Little Blackfoot River (control)	25	0.6	120	0.6	35	0.4	300	1.0

Source: Lambing, 1991.

Large amounts of the hazardous substance-containing material has been transported downstream by the Clark Fork River and deposited along banks and floodplains (Moore and Luoma, 1990; Nimick, 1990). Floodplain deposits act as continuous secondary sources to Clark Fork River bed sediments through erosion, runoff, and leaching of soluble substances into surface water or groundwater and subsequent deposition to sediments (Nimick, 1990). Thus contaminated floodplain soils are an important ongoing secondary source by which the Clark Fork River is continuously exposed to hazardous substances (ENSR, 1992; Lambing, 1991).

3.5 COMPARISON OF SEDIMENT CONCENTRATIONS OF HAZARDOUS SUBSTANCES AT FISH POPULATION STUDY SITES

In addition to sampling bed sediments in the Clark Fork River and its principal tributaries, bed sediments were collected (and hazardous substances analyzed) at 36 sites

in the Clark Fork River and in control rivers where fisheries populations were measured for injury quantification to fisheries (18 test sites in the Clark Fork River; 18 matched control sites — see Section 6.5 for site descriptions) (Essig and Moore, 1992). This work was performed in order to assess whether concentrations of hazardous substances in bed sediments at Silver Bow Creek and Clark Fork River test sites exceeded concentrations in sediments at fisheries control sites. One to eight sediment samples were collected at each site. Essig and Moore (1992) present the results of this sediment sampling and compares sediment hazardous substance concentrations between test and control sites. Mean sediment concentrations were calculated if more than one sediment sample was collected at a fish population site. Differences between the test and control pairs were assessed statistically. The results (Figures 3-20 through 3-24) show a highly significant ($p < .01$) elevation in sediment hazardous substance concentrations in the Clark Fork River and Silver Bow Creek relative to their matched controls. Concentrations of arsenic, cadmium, copper, and zinc were higher at all 18 test sites than at the matching controls. Lead concentrations were higher at 17 of the 18 controls.

Test and control stream sediments were also compared by calculating the ratio of the mean metals concentrations in the test stream to the mean concentrations in the control streams for each of the 18 pairs. Where concentrations in test and control streams are equal, ratios equal one. Ratios greater than one indicate the magnitude by which test stream concentrations exceed control stream concentrations. Ratios were calculated for As, Cd, Cu, Pb, and Zn for the 18 site pairs, and are presented as mean sediment metal elevation in test streams (Figure 3-25). The mean concentrations of both copper and cadmium in test sites exceeded mean concentrations in control sites by a factor of more than 70. Zinc concentrations at test sites exceeded concentrations at control sites by a factor of more than 25. Lead and arsenic concentrations at test sites exceeded those at control sites by factors of approximately 10 and 7, respectively. The overall conclusion to be drawn from this analysis is consistent with the other sediment analyses: bed sediments of Silver Bow Creek and the Clark Fork River are contaminated with hazardous substances at concentrations that greatly exceed concentrations at sites that support baseline fish populations (see Chapter 6.0).

3.6 PATHWAYS OF HAZARDOUS SUBSTANCES TO SILVER BOW CREEK AND CLARK FORK RIVER BED SEDIMENTS

As described in this chapter, the bed sediments of Silver Bow Creek and the Clark Fork River are highly contaminated with the hazardous substances arsenic, cadmium, copper, lead, and zinc. These hazardous substances originated from releases from mining and mineral processing operations in the Butte and Anaconda areas. The principal pathways by which sediments have been exposed to hazardous substances are surface water/sediment and groundwater pathways.

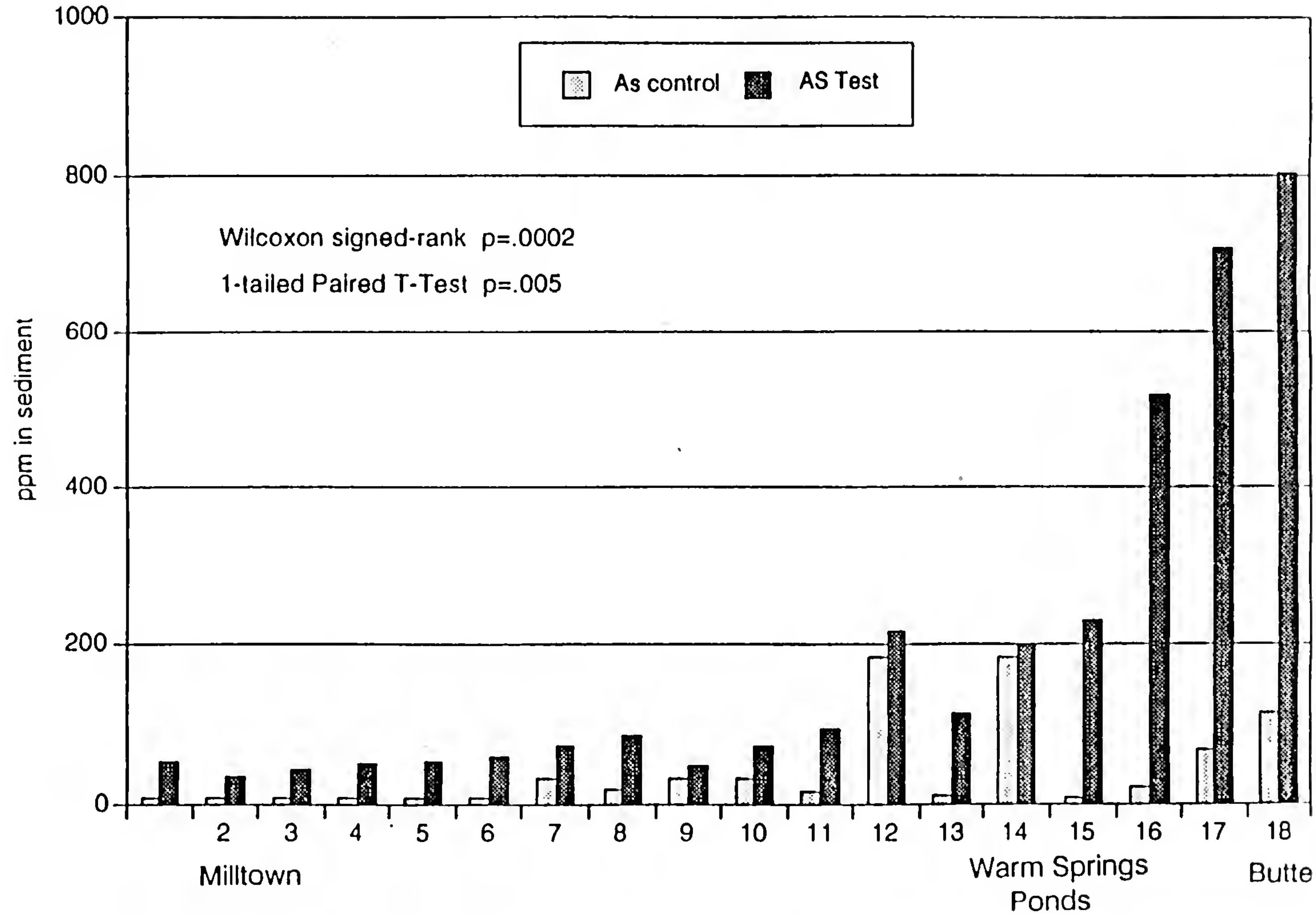

Figure 3-20. Sediment Arsenic by Stream Pairs. Source: Essig and Moore, 1992.

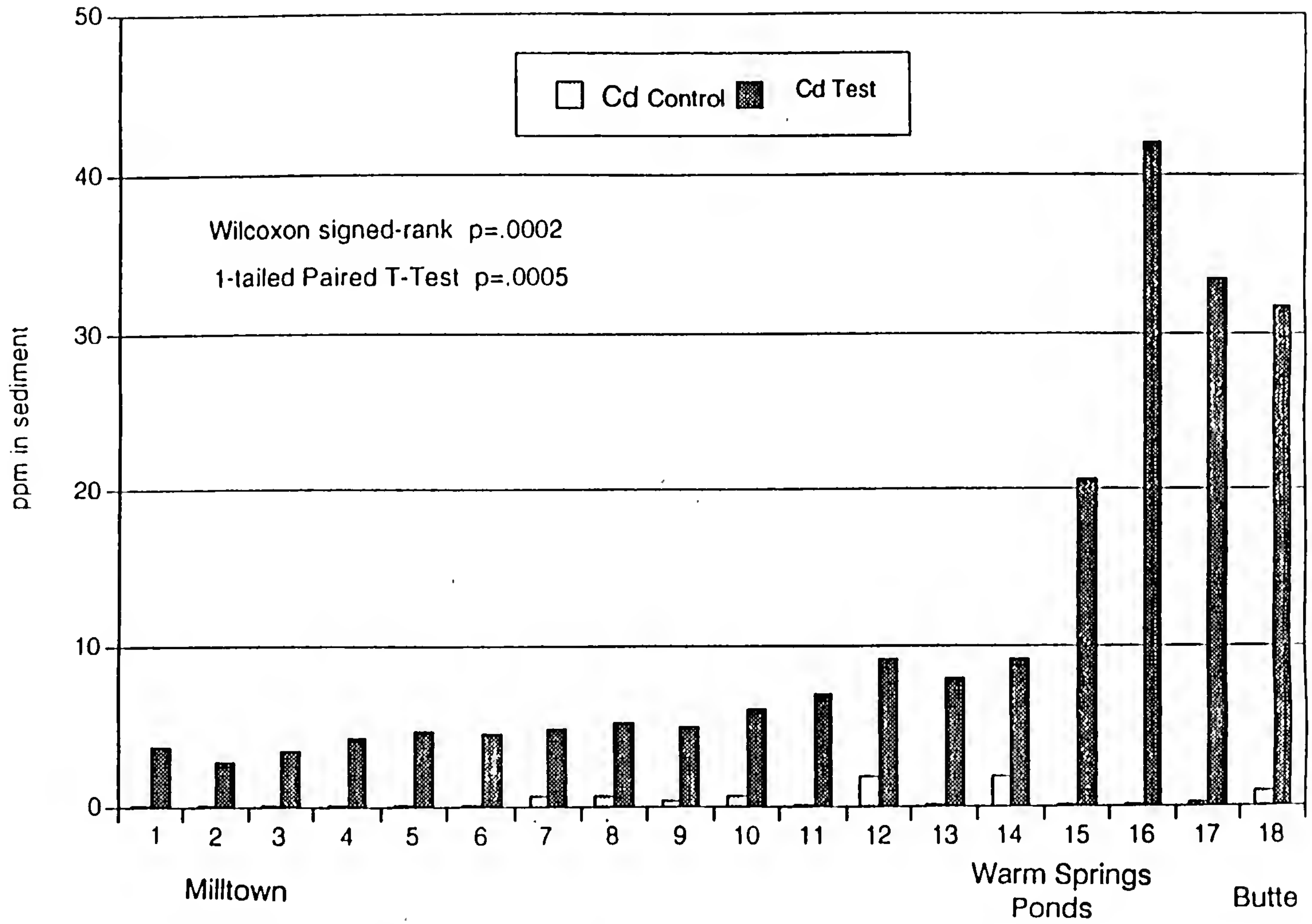

Figure 3-21. Sediment Cadmium by Stream Pairs. Source: Essig and Moore, 1992.

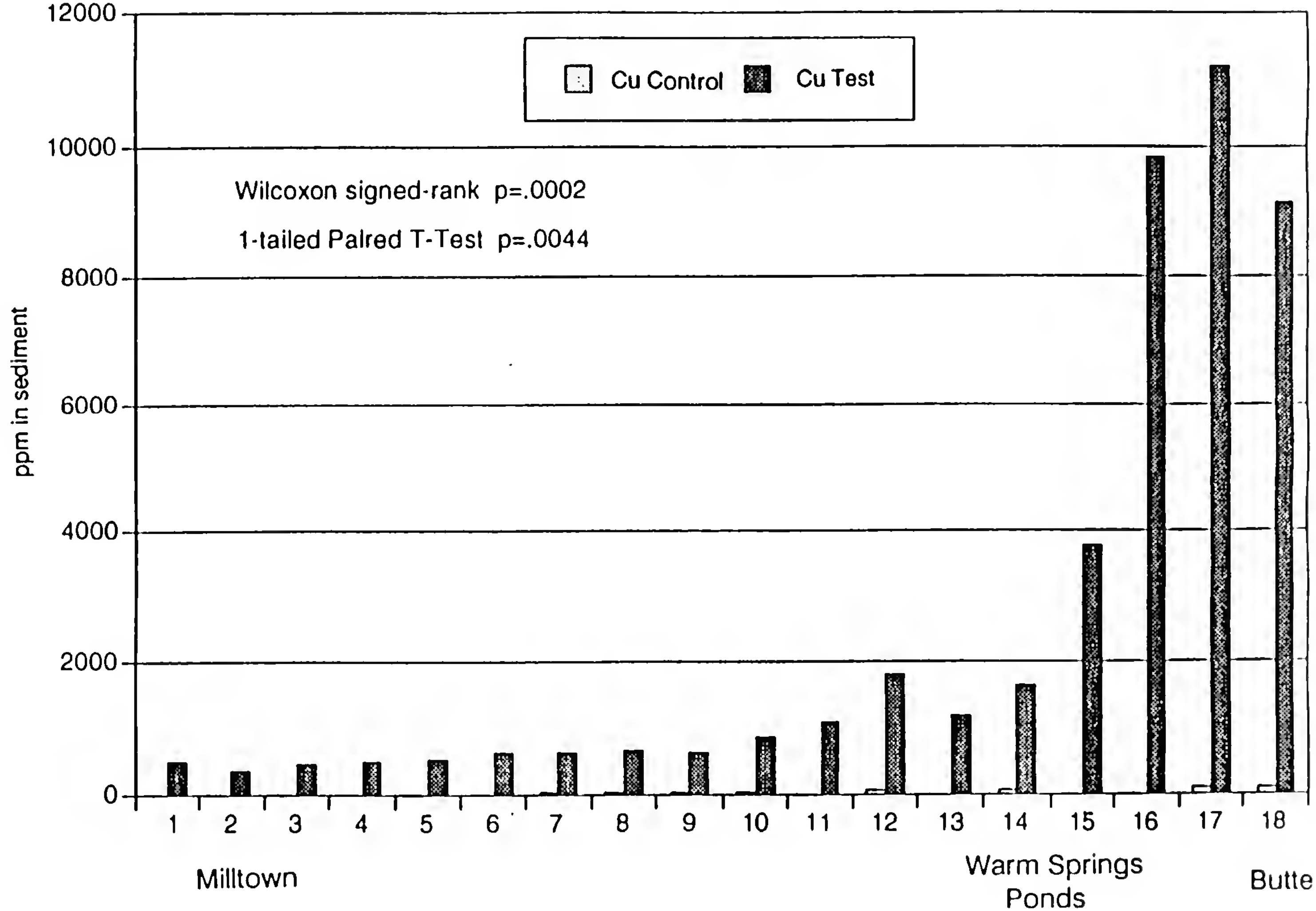

Figure 3-22. Sediment Copper by Stream Pairs. Source: Essig and Moore, 1992.

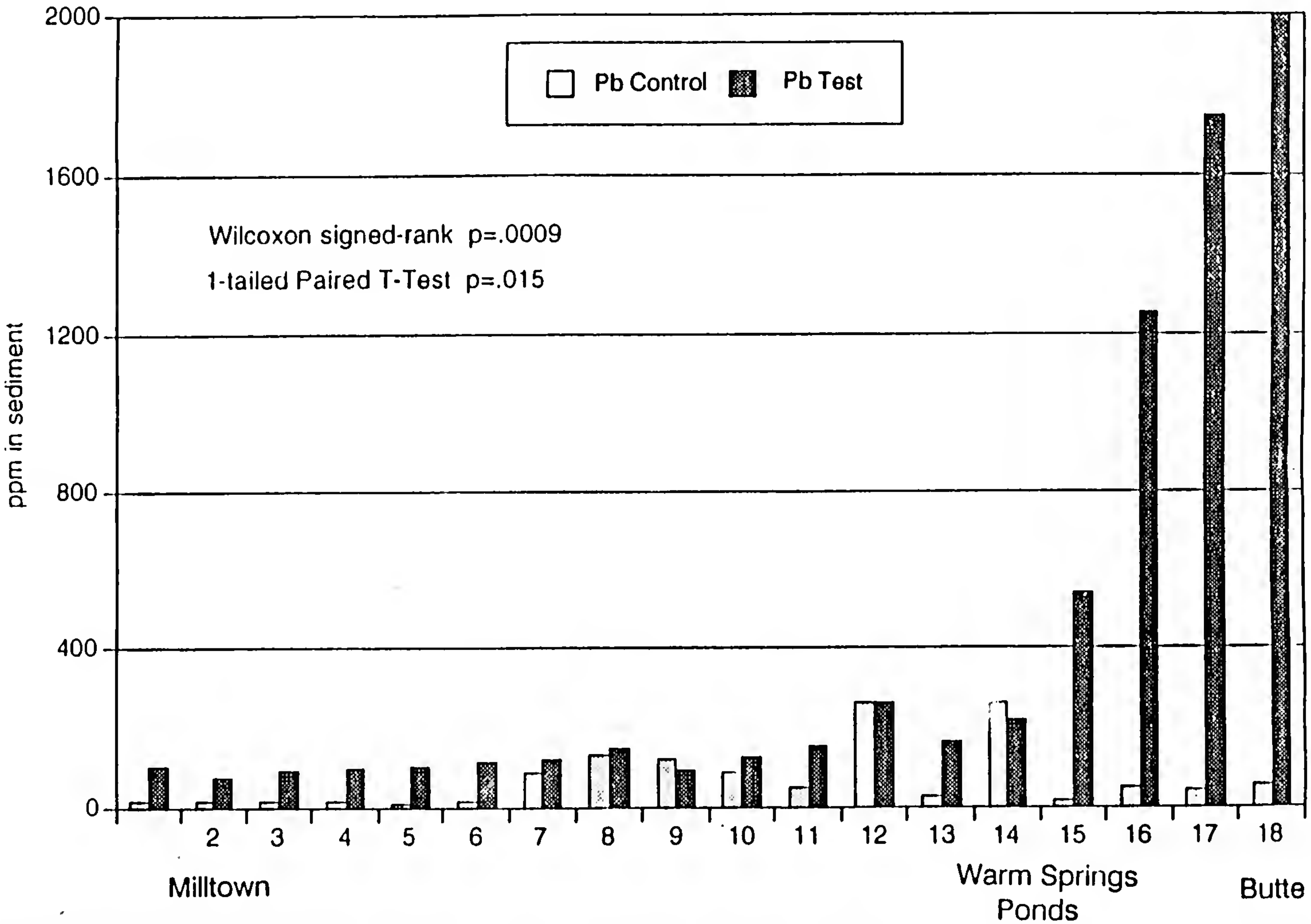

Figure 3-23. Sediment Lead by Stream Pairs. Source: Essig and Moore, 1992.

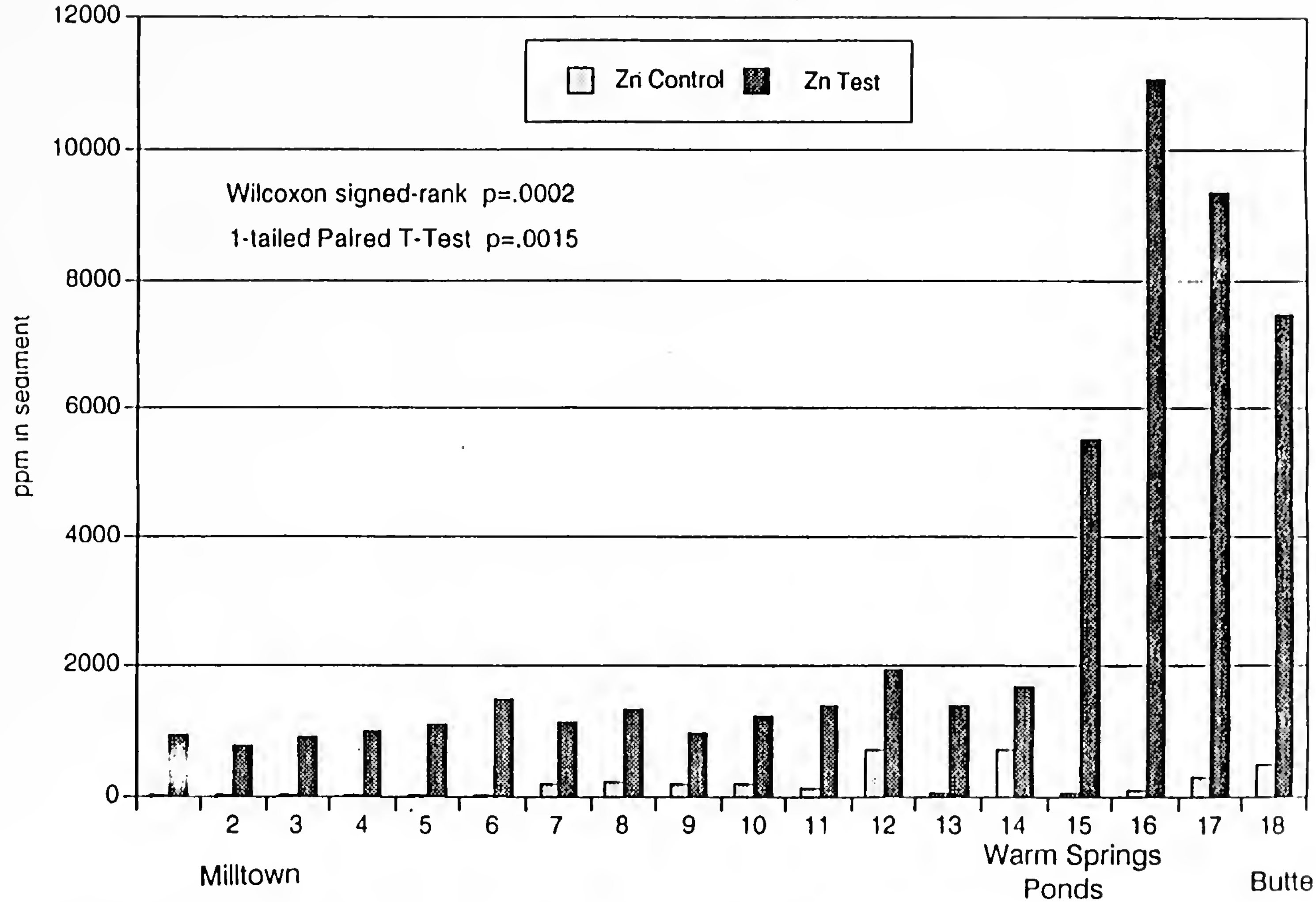

Figure 3-24. Sediment Zinc by Stream Pairs. Source: Essig and Moore, 1992.

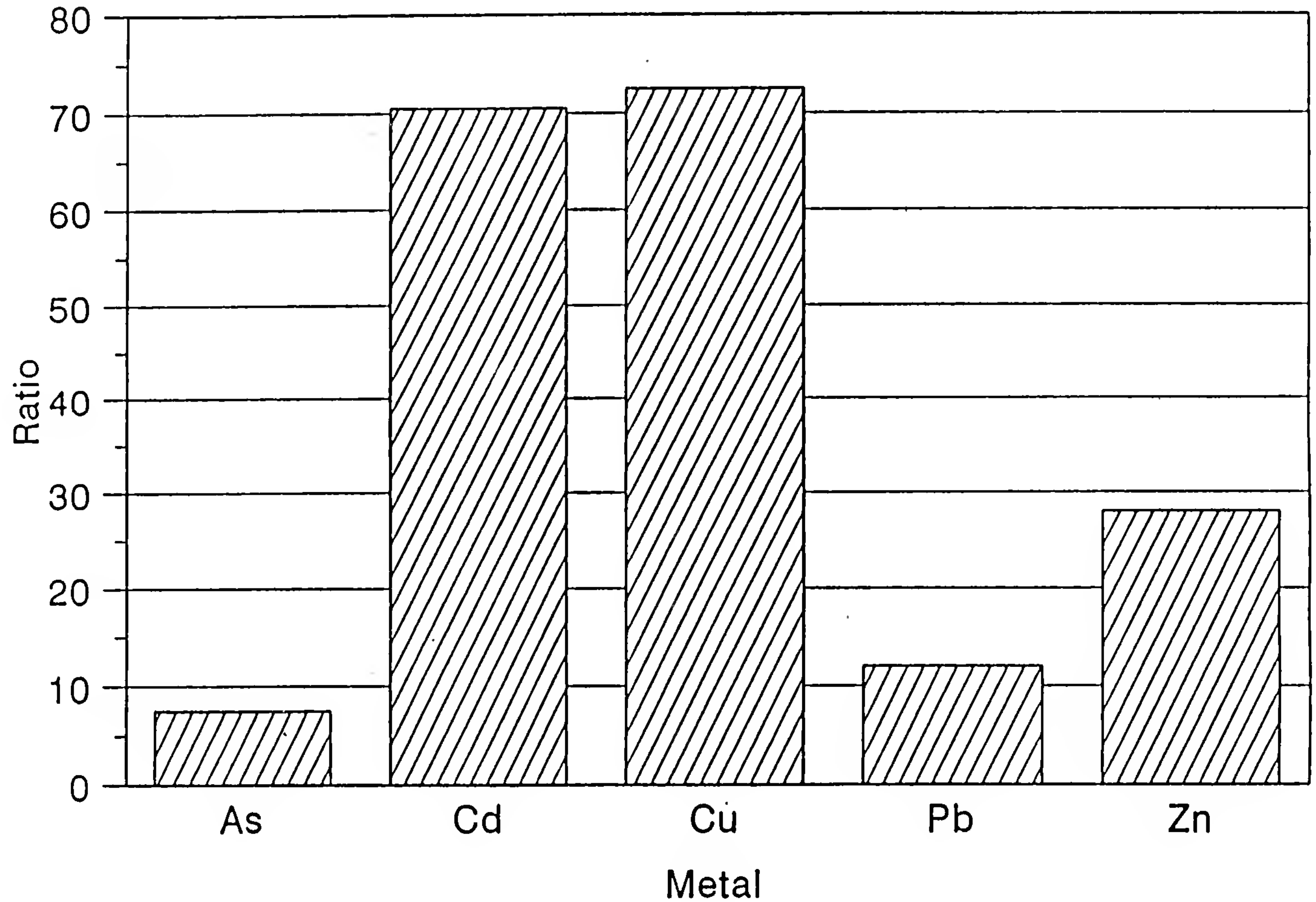

Figure 3-25. Mean Ratio of Test vs. Control Sediment Metals Concentrations. Source: Essig and Moore, 1992.

As described in Chapter 2.0, Silver Bow Creek received direct discharge of raw mining and mineral processing wastes containing hazardous substances. These direct discharges have been, and continue to be transported downstream in dissolved form, as suspended particulate matter, and as particulate bedload. Thus, both surface water and sediments act as pathways to downstream exposed areas (Andrews, 1987; Axtmann and Luoma, 1991; ENSR, 1992; Lambing, 1991; Moore and Luoma, 1990).

In addition to surface water/sediment pathways, groundwater acts as a pathway to exposed sediments. As described in Chapter 2.0, groundwater contaminated with hazardous substances discharges to Silver Bow Creek near Lower Area One. Some of these dissolved metals precipitate out of solution or become adhered to particulate matter as Silver Bow Creek gradually becomes less acidic as it moves downstream (Canonie, 1992).

3.7 CONCLUSIONS

The sediments of Silver Bow Creek, Warm Springs Ponds, and the Clark Fork River from Warm Springs to Milltown are highly contaminated with the hazardous substances arsenic, cadmium, copper, lead, and zinc as a result of large-scale mining and mineral processing operations in the Butte and Anaconda areas. No other significant sources of these hazardous substances are known to occur along Silver Bow Creek, the Clark Fork River, or their tributaries. Furthermore, the downstream decline of hazardous substance concentrations within the Clark Fork River and sediment "fingerprinting" studies also demonstrate that hazardous substances in sediments of Silver Bow Creek and the Clark Fork River originated from the Butte and Anaconda areas. Significant downstream transport of hazardous substances has been documented in studies of Silver Bow Creek and the Clark Fork River. These studies support the conclusion that upstream sources are responsible for downstream contamination. Finally, a dramatic and highly significant elevation in sediment hazardous substance concentrations occurs at the fish population sampling locations in Silver Bow Creek and the Clark Fork River relative to locations in control streams.

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4.0 SURFACE WATER

4.1 INTRODUCTION

This chapter presents the determination and quantification of injury to surface water resources of Silver Bow Creek and the Clark Fork River. In addition to having been injured by releases of hazardous substances, surface water serves as a primary transport pathway of metals to fish, and interacts closely, if not inseparably, with bed sediments in the migration of metals from upstream source areas to downstream reaches. The surface water chapter is organized as follows: Section 4.2 presents the results of injury determination; Section 4.3 quantifies those injuries and discusses the recoverability of the resource; Section 4.4 compares metals concentrations at fish population study sites in the injured resource to control fish study sites; and Section 4.5 discusses the pathways by which hazardous substances have migrated or have been transported from source areas to the surface waters of Silver Bow Creek and the Clark Fork River.

4.2 INJURY TO THE CLARK FORK BASIN SURFACE WATER RESOURCE

4.2.1 Injury Definition

Surface water resources of Silver Bow Creek and the Clark Fork River have been injured according to the following definitions:

- Concentrations and duration of substances in excess of applicable water quality criteria established by section 304(a)(1) of the CWA (Clean Water Act)...in surface water that before the discharge or release met the criteria and is a committed use...as a habitat for aquatic life, water supply, or recreation [43 CFR § 11.62 (b)(iii)].

- Concentrations and duration of hazardous substances sufficient to have caused injury to biological resources when exposed to surface water, suspended sediments, or bed, bank, or shoreline sediments [43 CFR § 11.62 (b)(v)].

4.2.2 Category of Injury: Exceedences of Ambient Water Quality Criteria

4.2.2.1 Criteria Definitions

Pursuant to Section 304(a)(1) of the Clean Water Act [33 U.S.C. 1314 (a)(1)], the U.S. Environmental Protection Agency (U.S. EPA) established ambient water quality criteria (AWQC) for the protection of aquatic life. These criteria represent concentrations of

substances which would cause unacceptable impacts to an aquatic community. AWQC have been established for over 100 substances, including cadmium, copper, lead, and zinc. These criteria have been adopted by the State of Montana as surface water quality standards. AWQC for these substances are expressed in terms of *acute* (one-hour average) and *chronic* (four-day average) criteria, which are not to be exceeded more than once every three years. This recovery period represents the average amount of time it takes a system to recover from a pollution event.

Criteria for cadmium, copper, lead and zinc are hardness-dependent (i.e., vary as the hardness of the water changes). Criteria for hard waters are higher than criteria for soft waters because metals tend to be more toxic at lower hardnesses. Criteria equations are presented in Table 4-1.

Table 4-1
Hardness-dependent Ambient Water Quality Criteria (AWQC)
(criteria calculated in µg/l)

Metal	Acute AWQC	Chronic AWQC
	Equation	Equation
Cadmium	$e^{(1.128\{\ln(\text{hardness})\}-3.828)}$	$e^{(0.7852\{\ln(\text{hardness})\}-3.490}$
Copper	$e^{(0.9422\{\ln(\text{hardness})\}-1.464)}$	$e^{(0.8545\{\ln(\text{hardness})\}-1.465)}$
Lead	$e^{(1.273\{\ln(\text{hardness})\}-1.460)}$	$e^{(1.273\{\ln(\text{hardness})\}-4.705)}$
Zinc	$e^{(0.8473\{\ln(\text{hardness})\}+0.8604)}$	$e^{(0.8473\{\ln(\text{hardness})\}+0.7614)}$

Although AWQC are expressed as one-hour and four-day *average* concentrations, surface water samples are usually collected as grab samples that characterize instantaneous concentrations. U.S. EPA guidance for determining designated uses for surface waters (U.S. EPA, 1991) states that aquatic life uses are *not supported* if acute or chronic criteria are violated more than once in a three-year period, based on grab or one-day composite samples. A statistical evaluation of grab sample datasets (Delos, 1990) supports this guidance. The evaluation concluded that if criteria are exceeded in 10% of grab samples, concentrations in water are *at least* an *order of magnitude* greater than should occur if criteria are not to be exceeded more than once every three years.[1]

[1] In other words, concentrations would be at least 10 times greater than if the criteria were met.

Using U.S. EPA guidance and supporting statistical analysis, the injury determination for surface water was based on the following criteria:

- Measurement of a minimum of two criteria exceedences in a three-year period, or

- Criteria exceedences in at least 10% of grab samples during the same three-year period.

The acceptance criterion for injury to the surface water resource is measurement of concentrations of a hazardous substance in two samples from the resource [43 CFR § 11.62 (b)(2)(i)]. Samples must be one of the following types:

- Two water samples from different locations not less than 100 feet apart
- Two water samples from the same location collected at different times.

Data used in the surface water injury determination meet the acceptance criteria. Data have been collected from numerous sampling locations in 120 miles (190 km) of the surface water resource over a period of many years.

4.2.2.2 Water Quality Data Analysis

The primary source of surface water data was U.S. EPA's national water quality database STORET (Storage Retrieval). Data in this system are provided by local, state, and federal agencies involved in the collection of surface water data. Data for the Clark Fork River basin originate primarily from monitoring programs conducted by the Montana Department of Health and Environmental Sciences (MDHES). Data are also derived from the U.S. Geological Survey (USGS), the U.S. EPA, RI/FS (Superfund Remedial Investigation/ Feasibility Study) documents, and other published reports.

STORET data were retrieved for Silver Bow Creek, the Clark Fork River, and tributary streams. Several long reaches which encompassed a large number of sampling sites were divided into smaller assessment units based on clusters of sampling sites. These reaches were the upper Clark Fork River between Warm Springs Ponds and the Little Blackfoot River (CFR6A-6E) and upper Silver Bow Creek between Butte and Durant Canyon below Miles Crossing (SBC9A-9C). Figure 4-1 and Table 4-2 summarize reach descriptions, station location information, and other pertinent information.

Acute and chronic criteria were calculated for cadmium, copper, lead, and zinc for samples which included a hardness concentration (or calcium and magnesium concentrations from which a hardness concentration could be calculated). A "severity index" was calculated by dividing the concentration of a metal by its acute or chronic

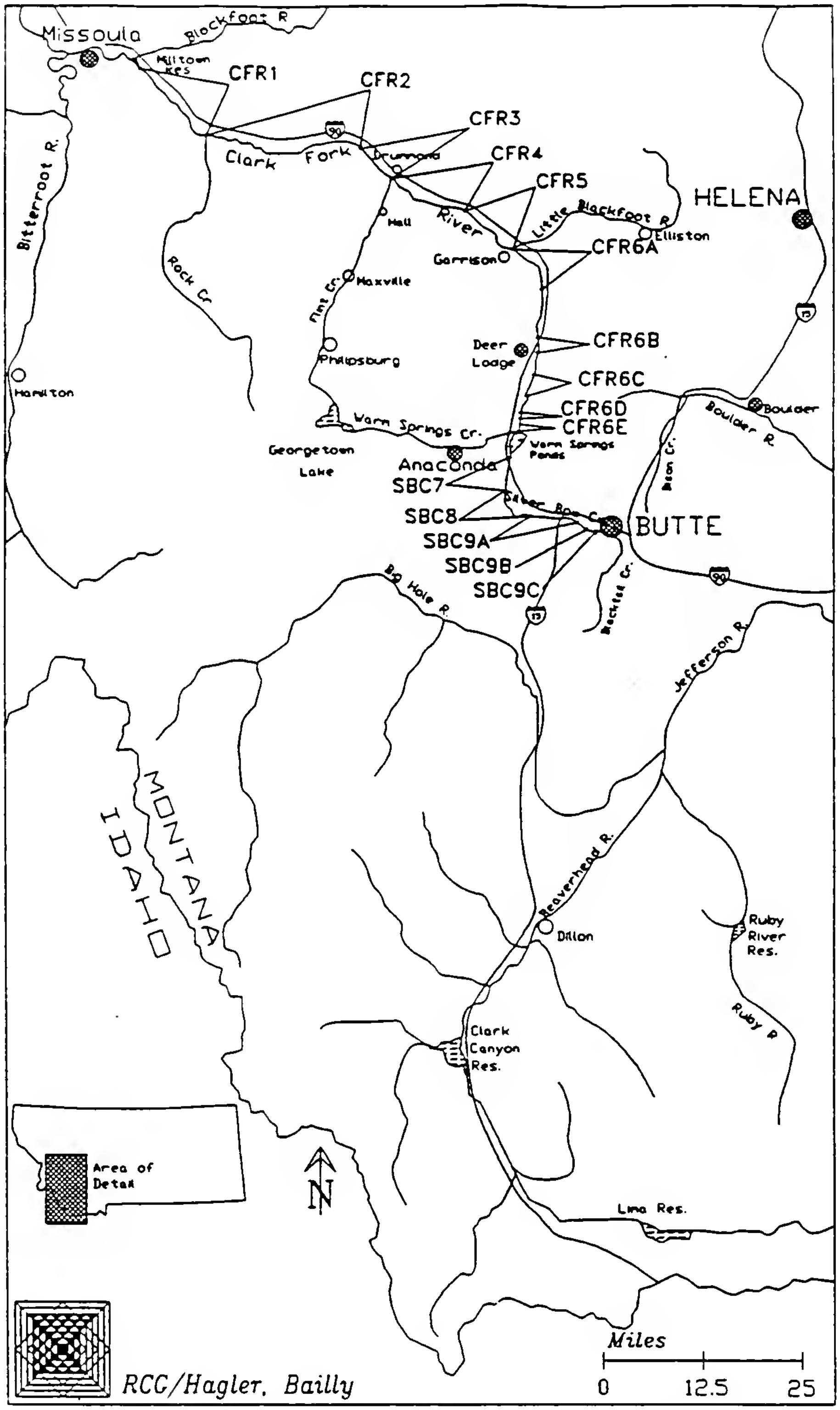

Figure 4-1. Surface Water Reach Locations, Silver Bow Creek and Clark Fork River.

Table 4-2
Reach Descriptions and Station Location Information*

Reach Description	Station Locations	Data Collection Agencies	Period of Record
CFR1 - Milltown Reservoir to Rock Creek	below Rock Creek, Turah	MDHES, USGS	1977 - 1992
CFR2 - Rock Creek to near Drummond	Bearmouth, Bonita	MDHES, U.S. EPA	1970 - 1991
CFR3 - near Drummond to Flint Creek	Drummond	MDHES, USGS, U.S. EPA	1970 - 1987
CFR4 - Flint Creek to Gold Creek	Gold Creek Bridge, Jens	MDHES	1973 - 1991
CFR5 - Gold Creek to Little Blackfoot River	near Garrison, Phosphate	MDHES, USGS, U.S. EPA	1968 - 1987
CFR6A - above Little Blackfoot River	Tavenner Ranch Bridge, Kohrs, near Beck Hill, above Little Blackfoot R.	MDHES, U.S. EPA	1970 - 1991
CFR6B - near Deer Lodge	Deer Lodge vicinity	MDHES, USGS	1968 - 1992
CFR6C - near Dempsey	near Dempsey, Racetrack Bridge, Sager Lane	MDHES, U.S. EPA	1970 - 1991
CFR6D - near Galen	Galen vicinity	MDHES, USGS	1971 - 1992
CFR6E - below Warm Springs Ponds	below Warm Springs Ponds	MDHES	1978 - 1991
SBC7 - Warm Springs Ponds to canyon bottom near Fairmont	Opportunity, Stewart Street Bridge, Fairmont Road, I-90 Frontage Road	MDHES, U.S. EPA	1970 - 1991
SBC8 - bottom to top of canyon	below German Gulch	MDHES	1978
SBC9A - top of canyon to Ramsay Flats area	Ramsay, Silver Bow, Rocker, Nissler, Miles Crossing	MDHES, U.S. EPA	1970 - 1991
SBC9B - below Colorado Tailings	below Colorado Tailings	MDHES	1976 - 1991
SBC9C - above Butte WWTP discharge	above Butte WWTP	MDHES	1988 - 1991

* Abbreviations: CFR (Clark Fork River); SBC (Silver Bow Creek).

criterion. This index is the factor by which a criterion is exceeded, with values greater than one representing criteria exceedences.

4.2.2.3 Review of Existing Data

The ability to "observe" exceedences of ambient water quality criteria depends on several factors, including:

- The frequency of sample collection
- The analytical detection limits
- The availability of hardness data necessary to calculate water quality criteria
- The method of sample digestion.

The first comprehensive characterization of water quality in Silver Bow Creek and the Clark Fork River was conducted by the U.S. EPA in 1970. Analytical detection limits for cadmium and lead at that time (10 to 50 times present-day detection limits) generally exceeded the ambient water quality criteria. However, ambient concentrations of copper and zinc were often high enough to be measurable and hence exceeded the criteria.

After 1970, water quality monitoring of Silver Bow Creek and the Clark Fork River that included hardness measurements occurred sporadically until 1985. Between 1972 and 1982, some reaches of the Clark Fork River had minimal or no sample collection (e.g., only four samples were collected from reach CFR3, only two from reach CFR6D, and none from reach CFR6E over this period). Reach CFR6B contains the most comprehensive dataset, because of a long-term monitoring station located at Deer Lodge. Samples have been collected almost continuously at Deer Lodge since 1970 (except for 1972 and 1976 when no samples were collected). Data from this reach thus provide the best characterization of water quality in the Clark Fork River over time.

In 1983, the frequency of sample collection in Silver Bow Creek and the Clark Fork River increased under monitoring programs established by MDHES. By 1986, many sampling station locations had been permanently established. Samples were collected at least monthly (approximately twice a month during spring runoff). In addition, the USGS collected samples at three stations on the Clark Fork River (Galen, Deer Lodge, and Turah) and on tributary streams. Thus, metals concentrations and exceedences of AWQC are based largely on data collected since 1983.

In addition to these data limitations, it should be noted that sample digestion methods are also important when evaluating AWQC exceedences. The U.S. EPA recommends using a "total recoverable" method (which uses hot acid for sample digestion) for evaluating AWQC. USGS and MDHES employ somewhat different methods for

measuring total recoverable metals; these methods likely recover a smaller fraction of sediment-bound metals than the U.S. EPA total recoverable method.[2] Therefore, the use of USGS and MDHES data to evaluate AWQC is conservative.

4.2.2.4 Injury to Silver Bow Creek: AWQC Exceedences

Data were collected from Silver Bow Creek at Ramsay and above Warm Springs Ponds by the U.S. EPA in 1970 and 1971. These data, summarized in Table 4-3, illustrate gross contamination by cadmium, copper, lead, and zinc. Tenfold, and even hundredfold, exceedences of cadmium and copper AWQC were common.

Table 4-4 summarizes criteria exceedences, by reach, for data collected since 1985, the earliest year of continuous data collection. These data demonstrate that hazardous substances in Silver Bow Creek have exceeded, and continue to exceed, aquatic life criteria. For example, 100% of samples collected in Silver Bow Creek (n=348 for all reaches combined) exceeded both the acute and chronic copper criteria (by factors as great as 84 and 132, respectively). All but one sample (n=344 for all reaches combined) exceeded both the acute and chronic zinc criteria (by factors as great as 42 and 47, respectively). The cadmium chronic criterion was exceeded in 57% (SBC7) to 87% (SBC9B) of samples. The lead chronic criterion was exceeded in 28% (SBC9C) to 91% (SBC7) of samples.

To illustrate the severity of injury to Silver Bow Creek, copper and zinc acute criteria exceedences are plotted for an upstream reach (SBC9B) and a downstream reach (SBC7) (Figure 4-2). The plots demonstrate that Silver Bow Creek has been injured continuously by extreme exceedences of copper and zinc AWQC.

4.2.2.5 Injury to the Clark Fork River: AWQC Exceedences

In 1970, the U.S. EPA collected water quality data at sampling stations located in reaches CFR3, CFR5, CFR6A, CFR6B, and CFR6C. Cadmium and lead concentrations were seldom above the analytical detection limits available at the time. Copper and zinc concentrations, while often in the hundreds of parts per billion, did not always exceed water quality criteria because of extremely high hardness concentrations caused by the liming of the Warm Springs Ponds. However, copper acute and chronic criteria were exceeded at all stations, and zinc criteria were exceeded at stations upstream of the Little Blackfoot River at Garrison. Metals concentrations from this study are summarized in Table 4-5.

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[2] The MDHES total recoverable method was found to measure significantly lower concentrations ($p<0.05$) of Cd, Cu, Pb, and Zn than the U.S. EPA method (Appendix A).

Table 4-3
Concentrations of Hazardous Substances and AWQC Exceedences in Silver Bow Creek, 1970-1971
(total metals concentrations in mg/l)[1,2]

Location	Cadmium		Copper		Lead		Zinc	
	Concen-tration Range	Magnitude of Criteria Exceedences	Concen-tration Range	Magnitude of Criteria Exceedences	Concen-tration Range	Magnitude of Criteria Exceedences	Concen-tration Range	Magnitude of Criteria Exceedences
Ramsay	1.3 - 3.0	8.8 - 15.6 (A) 98.6 - 176.2 (C)	20.5 - 49.0	52.2 - 179.8 (A) 108.6 - 345.6 (C)	0.175 - 0.970	0.0 - 0.3 (A) 0.9 - 8.1 (C)	34.0 - 120.0	12.2 - 93.0 (A) 13.5 - 102.6 (C)
Silver Bow Creek, above Warm Springs Ponds	<0.01 - 1.9	0.1 - 12.0 (A) 1.1 - 113.0 (C)	11.5 - 87.8	53.0 - 388.6 (A) 102.0 - 738.3 (C)	0.15 - 0.80	0.0 - 0.4 (A) 1.0 - 11.1 (C)	0.01 - 110.0	0.0 - 69.9 (A) 0.0 - 77.2 (C)

1 Criteria exceedence magnitudes are presented for both acute (A) and chronic (C) criteria. Magnitudes represent ratio of ambient concentration to criterion concentration; for example, a magnitude of 5.0 represents an ambient concentration five times the criterion.

2 Sample size ranges from 11 to 17 depending on location and metal analyzed.

Table 4-4
Frequency and Magnitude of AWQC Exceedences in Silver Bow Creek, 1985 - 1991

Criteria	Statistic	SBC7	SBC9A	SBC9B	SBC9C
Cadmium, acute	Number of samples	51	47	46	43
	Percentage exceeding criteria	4	2	2	2
	Magnitude of exceedences[1]	1 - 3	1	1	1 - 19
Cadmium, chronic	Number of samples	51	47	46	43
	Percentage exceeding criteria	57	77	87	60
	Magnitude of exceedences	1 - 14	1 - 5	1 - 5	1 - 65
Copper, acute	Number of samples	97	91	88	72
	Percentage exceeding criteria	100	100	100	100
	Magnitude of exceedences	3 - 84	3 - 64	4 - 31	1 - 46
Copper, chronic	Number of samples	97	91	88	72
	Percentage exceeding criteria	100	100	100	100
	Magnitude of exceedences	5 - 132	5 - 101	6 - 47	2 - 68
Lead, chronic	Number of samples	45	45	44	46
	Percentage exceeding criteria	91	89	61	28
	Magnitude of exceedences	1 - 27	1 - 12	1 - 12	1 - 21
Zinc, acute	Number of samples	97	91	88	68
	Percentage exceeding criteria	99	100	100	99
	Magnitude of exceedences	1 - 42	2 - 19	4 - 14	2 - 14
Zinc, chronic	Number of samples	97	91	88	68
	Percentage exceeding criteria	99	100	100	99
	Magnitude of exceedences	1 - 47	2 - 20	4 - 16	2 - 16

[1] Measured concentration divided by calculated AWQC.

Source: STORET; MDHES, 1990, 1991.

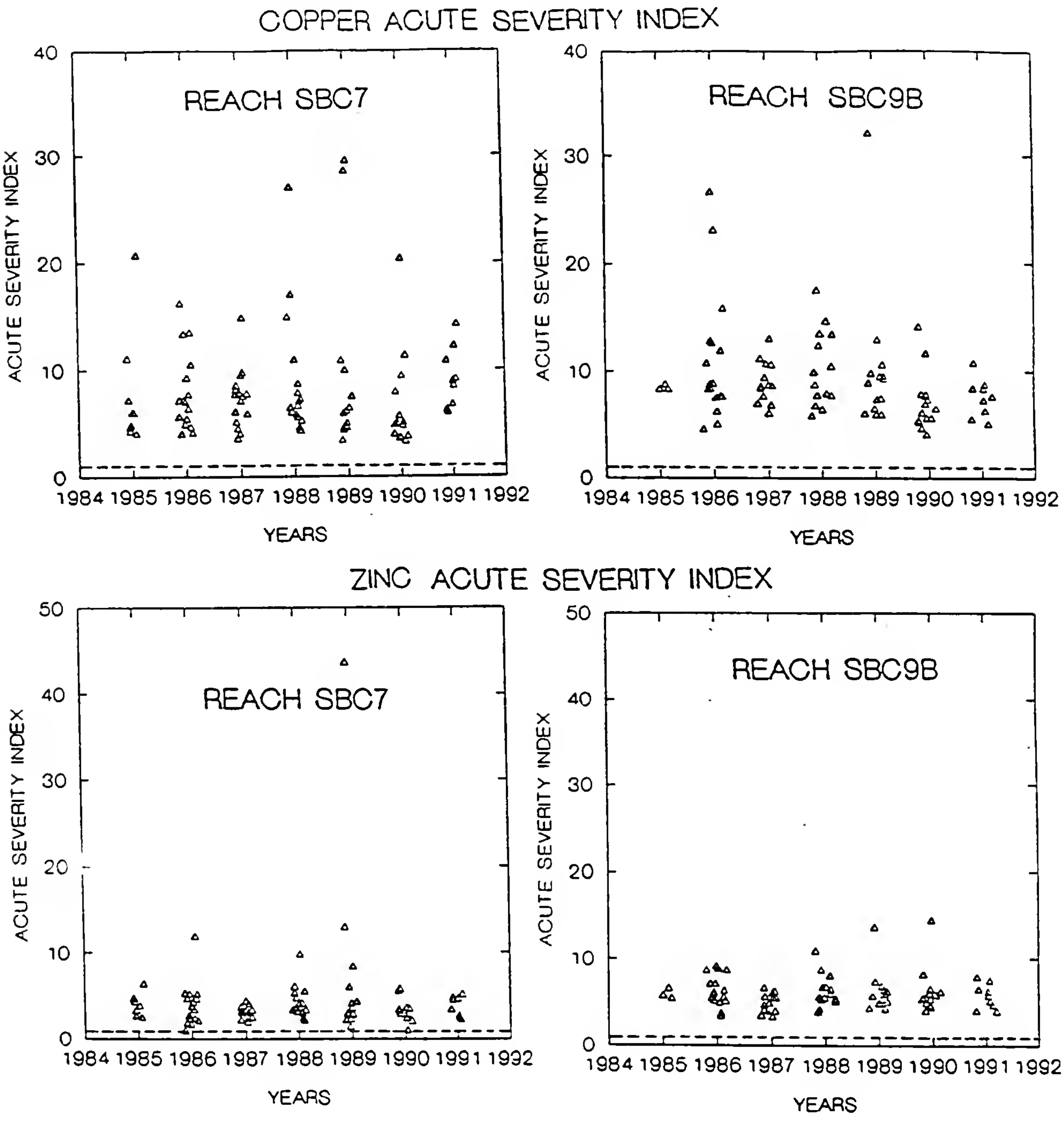


Figure 4-2. Copper and Zinc Acute Severity Indices, Reaches SBC7 and SBC9B. Index values greater than one indicate concentrations in excess of ambient water quality criteria.

Table 4-5
Concentrations of Hazardous Substances and AWQC Exceedences in the Clark Fork River, 1970-1971
(total metals concentrations in $\mu g/l$)[1]

	Copper		Zinc	
Location	**Concentration Range**	**Magnitude of Criteria Exceedences**	**Concentration Range**	**Magnitude of Criteria Exceedences**
Dempsey (CFR6C)	40 - 400	0.2 - 4.1 (A) 0.4 - 7.2 (C)	90 - 960	0.1 - 1.8 (A) 0.3 - 1.9 (C)
Deer Lodge (CFR6B)	20 - 1,200	0.2 - 13.3 (A) 0.3 - 23.2 (A)	70 - 4,700	0.1 - 9.3 (A) 0.1 - 10.3 (C)
Tavenner Bridge (CFR6A)	30 - 460	0.2 - 4.0 (A) 0.4 - 7.2 (C)	60 - 500	0.1 - 1.2 (A) 0.1 - 1.3 (C)
Garrison (CFR5)	20 - 240	0.2 - 2.1 (A) 0.3 - 3.8 (C)	30 - 290	0.0 - 0.7 (A) 0.0 - 0.8 (C)
Drummond (CFR3)	40 - 90	0.4 - 1.1 (A) 0.7 - 1.8 (C)	40 - 250	0.1 - 0.6 (A) 0.1 - 0.6 (C)

1 Criteria exceedence magnitudes presented for both acute (A) and chronic (C) criteria.

Between 1971 and 1983, only the Deer Lodge location was continuously sampled in the Clark Fork River. By 1985, all reaches except CFR3, CFR5, and CFR6D were sampled at least monthly by MDHES.

Figures 4-3 through 4-6 illustrate the occurrence of copper criteria exceedences for a representative reach of the lower, middle, and upper Clark Fork River, and for reach CFR6B (the long-term monitoring station at Deer Lodge). Acute and chronic severity indices are plotted for the years of record. The figures indicate that criteria exceedences have occurred regularly throughout the period of record; in most reaches criteria exceedences have been documented almost yearly. Further, the plots show no evidence of a decline in either the frequency or magnitude of criteria exceedences over time. The overall conclusion to be drawn from these figures is that the entire river has been injured continuously by releases of copper.

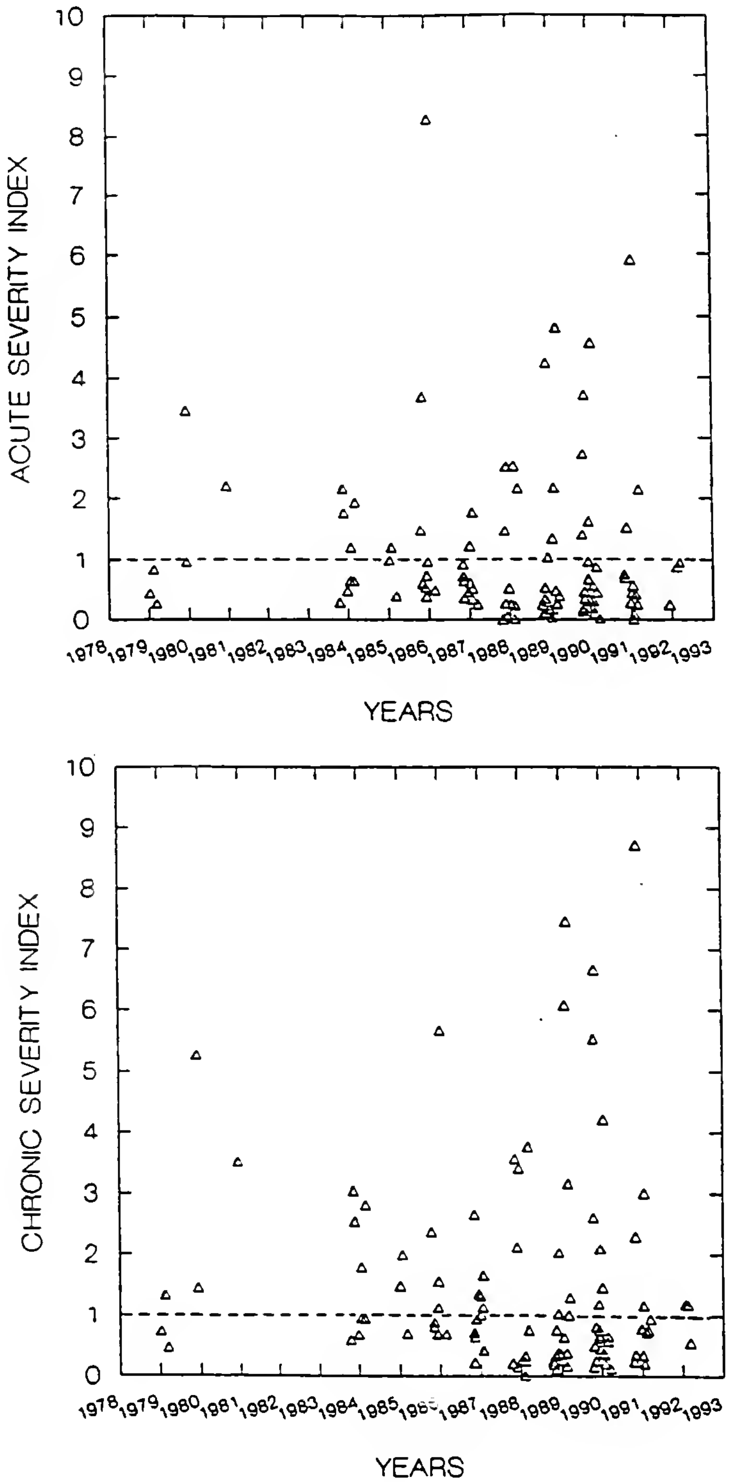


Figure 4-3. **Copper Acute and Chronic Severity Indices, Lower Clark Fork River (Reach CFR1).** Index values greater than one indicate concentrations in excess of ambient water quality criteria.

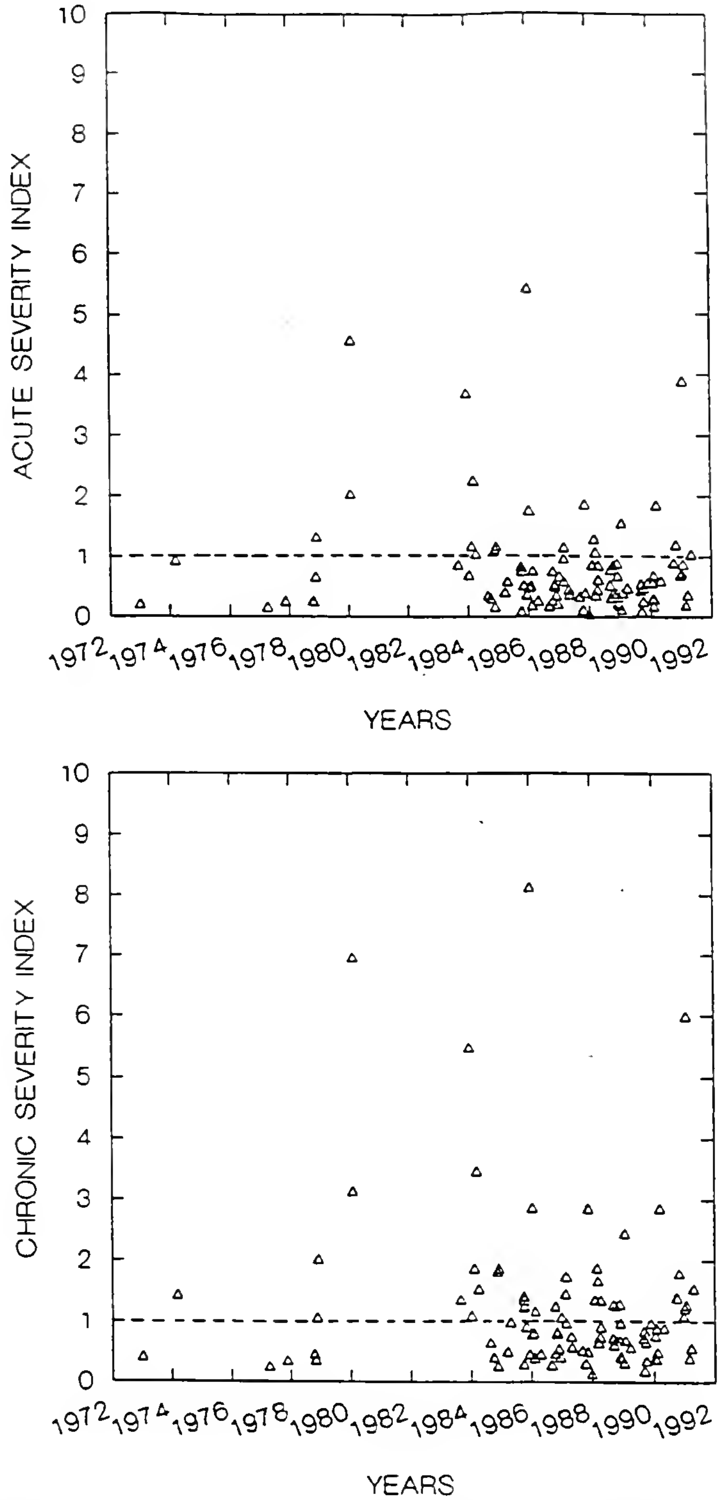
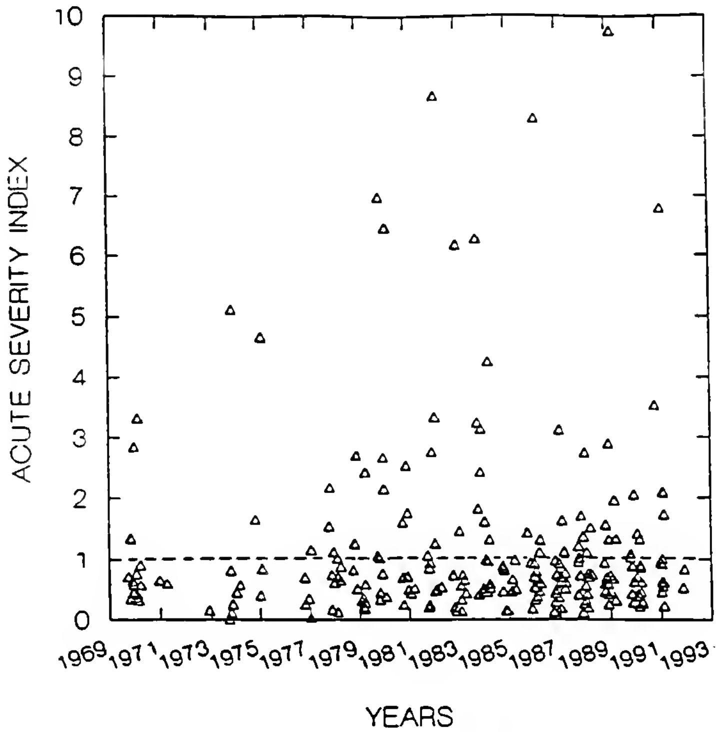


Figure 4-4. Copper Acute and Chronic Severity Indices, Middle Clark Fork River (Reach CFR4). Index values greater than one indicate concentrations in excess of ambient water quality criteria.



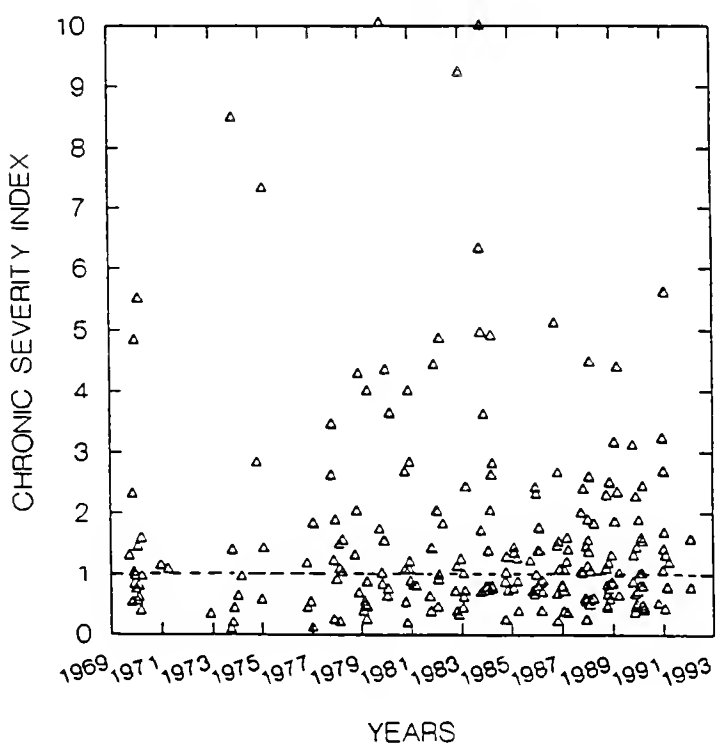


Figure 4-5. Copper Acute and Chronic Severity Indices, Upper Clark Fork River (Reach CFR6B). Index values greater than one indicate concentrations in excess of ambient water quality criteria.

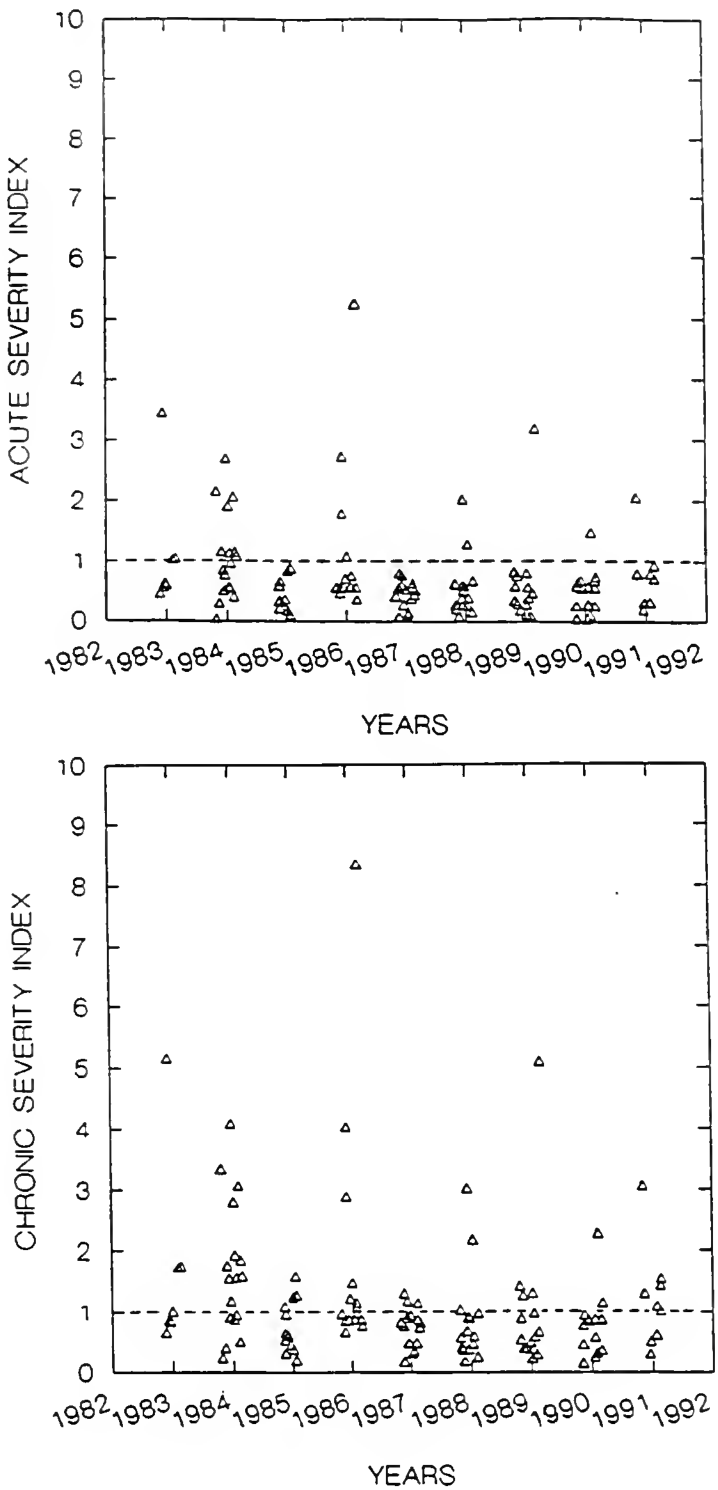


Figure 4-6. Copper Acute and Chronic Severity Indices, Upper Clark Fork River (Reach CFR6E). Index values greater than one indicate concentrations in excess of ambient water quality criteria.

Documented criteria exceedences for cadmium, copper, lead, and zinc are tabulated by year and by reach in Tables 4-6 through 4-9 for the period 1970 — 1992. The reaches and years for which the injury criteria (at least two criteria exceedences in three years, or exceedences in 10% of samples collected) were met are highlighted. Based on the extent and frequency of criteria exceedences, including exceedences of acute criteria, copper is the most frequent cause of injury to Clark Fork River surface water. In general, conditions in the Clark Fork River are characterized by multiple exceedences which occur yearly in all reaches (where monitoring has been conducted intensively). In addition to copper, the chronic lead criterion has been exceeded regularly. Cadmium and zinc concentrations exceed criteria less frequently, although chronic criteria for both have been exceeded in the upper portion of the river (CFR6A-6E).

Again, the approach for determining injury for the Clark Fork River is conservative for several reasons:

- Most hazardous substance concentrations were derived by the Montana total recoverable method, which recovers significantly less of the substance than the recommended U.S. EPA total recoverable method.

- The 10% excursion frequency for chronic criteria exceedences is <u>at least</u> one *order of magnitude* greater than could be justified by statistical analysis (Delos, 1990).

- Injury determination is likely limited only by the ability of small datasets (i.e., lack of monitoring intensity) to detect criteria exceedences.

4.2.2.6 Criteria Exceedences: Statistical Approach

An alternative approach was employed to assess exceedences of chronic water quality criteria in the Clark Fork River. Rather than using the determinative criteria applied above (i.e., > 10% exceedence frequency in grab samples or ≥ two exceedences in a three-year period), a statistical approach was employed to assess the likelihood of exceeding the chronic AWQC for copper over the period 1976 - 1992.

Water quality data for the Deer Lodge, Gold Creek, and Turah Bridge sites collected during high flow months (May and June) were assembled for the period 1976 - 1992 and the percentage of measurements that exceeded the chronic copper criterion was calculated. The hypergeometric distribution[3] was then used to calculate the probability

[3] The hypergeometric distribution describes the probability of obtaining consecutive "hits" (i.e., exceedences of the copper criterion) when sampling without replacement given the observed probability of a "hit."

Table 4-6a
Cadmium Criteria Exceedences in the Clark Fork River

(Value indicates number of chronic exceedences. Value in ( ) is percent of samples that exceeded chronic AWQC.
* = Injury criteria met. + = Injury by recovery time violation. ☐ = No data available.)

Reach	Year																							% Exceeding Acute Criterion
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	
CFR1								0 (0)	0 (0)	0 (0)		0 (0)		1* (100)	0+ (0)	0+ (0)	3* (50)	0+ (0)	0+ (0)	2* (8)	0+ (0)	1+ (8)	0 (0)	2
CFR2								0 (0)	0 (0)	0 (0)						0 (0)	0 (0)		0 (0)	0 (0)	0 (0)	0 (0)		0
CFR3	0 (0)	0 (0)	0 (0)		0 (0)											0 (0)								0
CFR4				0 (0)	0 (0)			0 (0)	0 (0)	0 (0)						0 (0)	0 (0)		0 (0)	0 (0)	0 (0)	0 (0)		0
CFR5	1* (10)	0+ (0)	+		0 (0)	0 (0)																		0
CFR6A	0 (0)	0 (0)								0 (0)				0 (0)	2* (100)	0+ (0)	0+ (0)		0 (0)	0 (0)	0 (0)	0 (0)		0
CFR6B	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)					1* (11)	1+ (9)	0+ (0)	1 (5)	3* (14)	0+ (0)	3* (13)	1+ (5)	1+ (7)	0 (0)	0
CFR6C	1* (10)	0+ (0)	+													0 (0)	0 (0)		0 (0)	0 (0)	0 (0)	0 (0)		0
CFR6D			1* (100)	+	+														0 (0)	2* (25)	1+ (11)	0+ (0)	0 (0)	0
CFR6E														2* (20)	0+ (0)	0+ (0)	0 (0)		0 (0)	1 (7)	0 (0)	0 (0)		0

Table 4-6b
Cadmium Criteria Exceedences in Silver Bow Creek

(Value indicates number of chronic exceedences. Value in ( ) is percent of samples that exceeded chronic AWQC.
*** = Injury criteria met. + = Injury by recovery time violation. ☐ = No data available.)**

Reach	Year																						% Exceeding Acute Criterion
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	
SBC7	9* (90)	1* (100)	+	+												0 (0)	0 (0)		3* (100)	12* (80)	7* (47)	7* (78)	+	19
SBC9A	10* (100)	1* (100)	+	+												0 (0)	0 (0)		3* (100)	15* (100)	11* (73)	7* (78)	+	21
SBC9B																0 (0)	0 (0)		3* (100)	14* (100)	14* (93)	9* (100)	+	2
SBC9C																			3* (100)	12* (75)	9* (60)	2* (22)	+	2

Table 4-7a
Copper Criteria Exceedences in the Clark Fork River

(Value indicates number of chronic exceedences. Value in ( ) is percent of samples that exceeded chronic AWQC. * = Injury criteria met. + = Injury by recovery time violation. □ = No data available.)

Reach	Year																							% Exceeding Acute Criterion
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	
CFR1								0 (0)	0 (0)	1* (25)	2* (50)	1* (100)	+	0+ (0)	4* (40)	2* (29)	9* (41)	6* (29)	4* (24)	7* (29)	7* (33)	4* (33)	2* (67)	23
CFR2								0 (0)	0 (0)	3* (38)	4* (100)	+	+		5* (83)	4* (36)	6* (35)	4* (25)	1+ (7)	2* (13)	4* (27)	3* (33)	+	19
CFR3	9* (90)	1* (100)	0+ (0)	+	1* (33)	+	+								5* (83)	2* (67)	+	+						17
CFR4				0 (0)	1* (100)	+	+	0 (0)	0 (0)	1* (25)	2* (100)	+	+		5* (83)	2* (29)	8* (47)	4* (25)	5* (33)	4* (25)	1+ (7)	6* (67)	+	16
CFR5	10* (71)	0+ (0)	+	+	0 (0)	3* (100)	+	+							5* (83)	+	+							33
CFR6A	11* (69)	1* (100)	+	+						2* (66)	2* (100)	+	+	6* (66)	13* (76)	4* (33)	9* (53)	6* (33)	8* (53)	5* (33)	6* (43)	8* (89)	+	28
CFR6B	7* (41)	2* (100)	+	0+ (0)	2* (29)	3* (75)	+	2* (29)	6* (55)	4* (33)	7* (70)	5* (45)	7* (58)	5* (42)	10* (59)	4* (33)	9* (45)	9* (43)	11* (58)	12* (55)	9* (41)	9* (69)	1* (50)	28
CFR6C	8* (50)	1* (100)	+	+							1* (100)	+	+			2* (22)	5* (33)	2* (13)	3* (19)	4* (18)	9* (30)	10* (56)	+	14
CFR6D			1* (100)	+	+					0 (0)							0 (0)		0 (0)	6* (75)	7* (78)	3* (75)	1* (50)	32
CFR6E														4* (40)	11* (65)	4* (33)	7* (41)	2* (13)	2* (13)	5* (33)	2* (13)	4* (44)	0+ (0)	14

Table 4-7b
Copper Criteria Exceedences in Silver Bow Creek

(Value indicates number of chronic exceedences. Value in ( ) is percent of samples that exceeded chronic AWQC.
* = Injury criteria met. + = Injury by recovery time violation. ☐ = No data available.)

Reach	Year																							% Exceeding Acute Criterion
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	
SBC7	16* (100)	1* (100)	+	+												9* (100)	17* (100)	16* (100)	16* (100)	15* (100)	15* (100)	9* (100)	+	100
SBC9A	15* (100)	1* (100)	+	+												3* (100)	17* (100)	15* (100)	17* (100)	15* (100)	15* (100)	9* (100)	+	100
SBC9B																3* (100)	17* (100)	15* (100)	15* (100)	14* (100)	15* (100)	9* (100)	+	100
SBC9C																		16* (100)	16* (100)	16* (100)	15* (100)	9* (100)	+	100

Table 4-8a
Lead Criteria Exceedences in the Clark Fork River

(Value indicates number of chronic exceedences. Value in ( ) is percent of samples that exceeded chronic AWQC. * = Injury criteria met. + = Injury by recovery time violation. ☐ = No data available.)

Reach	Year																							% Exceeding Acute Criterion
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	
CFR1								0 (0)	0 (0)			0 (0)		0 (0)		0 (0)	2* (100)	4* (80)	3* (33)	4* (18)	4* (19)	3* (23)	0+ (0)	0
CFR2								0 (0)	0 (0)										0 (0)	1 (7)	2* (13)	2* (22)	+	0
CFR3	1* (10)	1* (100)	0+ (0)	+	0 (0)																			0
CFR4								0 (0)	0 (0)										0 (0)	1 (7)	1 (7)	1* (11)	+	0
CFR5	1 (7)	0 (0)			0 (0)	0 (0)																		0
CFR6A	1 (6)	0 (0)												2* (20)	2* (17)	0+ (0)	+		0 (0)	1 (7)	1 (7)	3* (33)	+	0
CFR6B	2* (12)	1* (50)	+	+	0 (0)	0 (0)		0 (0)	1* (13)	+	+			3* (38)	3* (25)	0+ (0)	1+ (6)	1 (5)	2* (11)	4* (19)	1+ (5)	3* (23)	0+ (0)	0
CFR6C	2* (13)	1* (100)	+	+												0 (0)			0 (0)	1 (5)	0 (0)	2* (11)	+	0
CFR6D			0 (0)																0 (0)	4* (50)	2* (22)	2* (40)	0+ (0)	0
CFR6E														1 (9)	3* (27)	0+ (0)	+		0 (0)	1 (7)	0 (0)	2* (22)	0+ (0)	0

Table 4-8b
Lead Criteria Exceedences in Silver Bow Creek

(Value indicates number of chronic exceedences. Value in ( ) is percent of samples that exceeded chronic AWQC.
* = Injury criteria met. + = Injury by recovery time violation. ☐ = No data available.)

	Year																						% Exceeding
Reach	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	Acute Criterion
SBC7	15* (94)	1* (100)	+	+															6* (100)	14* (93)	12* (80)	9* (100)	+	0
SBC9A	12* (80)	1* (100)	+	+															6* (100)	13* (87)	12* (80)	9* (100)	+	0
SBC9B																			5* (83)	6* (43)	7* (47)	9* (100)	+	0
SBC9C																			0 (0)	3* (19)	2* (13)	8* (89)	+	0

Table 4-9a
Zinc Criteria Exceedences in the Clark Fork River

(Value indicates number of chronic exceedences. Value in ( ) is percent of samples that exceeded chronic AWQC.
* = Injury criteria met. + = Injury by recovery time violation. ☐ = No data available.)

Reach	Year																							% Exceeding Acute Criterion
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	
CFR1								0 (0)	0 (0)	0 (0)	1* (50)	0+ (0)	+	0 (0)	0 (0)	0 (0)	5* (23)	0+ (0)	0+ (0)	4* (17)	2* (10)	1+ (8)	0+ (0)	10
CFR2								0 (0)	0 (0)	0 (0)	2* (5)	+	+		1* (17)	0+ (0)	1+ (6)	0 (0)	0 (0)	0 (0)	1 (7)	0 (0)		3
CFR3	0 (0)	0 (0)	0 (0)		0 (0)										0 (0)	0 (0)								0
CFR4				0 (0)	0 (0)			0 (0)	0 (0)	0 (0)	1* (50)	+	+		0 (0)	0 (0)	1 (6)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2
CFR5	0 (0)	0 (0)			0 (0)	0 (0)									0 (0)									0
CFR6A	2* (13)	0+ (0)	+							0 (0)	1* (50)	+	+	0 (0)	1 (6)	0 (0)	1 (6)	1 (6)	0 (0)	0 (0)	0 (0)	1* (11)	+	3
CFR6B	3* (20)	0+ (0)	+	0 (0)	0 (0)	1* (25)	+	0+ (0)	0 (0)	0 (0)	2* (18)	0+ (0)	1+ (8)	0 (0)	0 (0)	0 (0)	3* (15)	0+ (0)	0+ (0)	3* (13)	1+ (5)	2* (14)	0+ (0)	5
CFR6C	1 (6)	0 (0)									1* (100)	+	+			0 (0)	1 (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)		2
CFR6D			1* (100)	+	+					0 (0)							0 (0)		0 (0)	1* (13)	1* (11)	1* (20)	0+ (0)	7
CFR6E														0 (0)	1 (6)	0 (0)	1 (6)	0 (0)	0 (0)	1 (7)	0 (0)	0 (0)		2

Table 4-9b
Zinc Criteria Exceedences in Silver Bow Creek

(Value indicates number of chronic exceedences. Value in ( ) is percent of samples that exceeded chronic AWQC.
*** = Injury criteria met. + = Injury by recovery time violation. ☐ = No data available.)**

Reach	Year																							% Exceeding Acute Criterion
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	
SBC7	15* (94)	1* (100)	+	+												9* (100)	17* (100)	16* (100)	16* (100)	15* (100)	15* (100)	9* (100)	+	99
SBC9A	14* (100)	1* (100)	+	+												3* (100)	17* (100)	15* (100)	17* (100)	15* (100)	15* (100)	9* (100)	+	100
SBC9B																3* (100)	17* (100)	15* (100)	15* (100)	14* (100)	15* (100)	9* (100)	+	100
SBC9C																		15* (100)	15* (100)	13* (100)	15* (100)	9* (100)	+	99

of selecting four consecutive samples, at random, that each exceeded the chronic criterion over a three-year period (again, the chronic criterion is a *four-day* average value not to be exceeded more than once over a three-year period).[4] In this analysis, only discrete (i.e., non-overlapping) four-day periods were considered.[5] The statistical method was applied to the months of May and June; therefore. a three-year period contains approximately 45 four-day periods (3 years x 61 days/4 days per period ≈ 45).

For each site, the likelihood of exceeding the chronic copper criterion was calculated. It should be noted that any concentrations below detection limits were deemed a "miss" (i.e., did not exceed the criterion), except if the detection limit exceeded the criterion; in that case the observation was deleted. In addition, to be conservative, if multiple observations were available for a given reach within a three-day period, the observation with the highest value was dropped from the analysis.

The results of this analysis are presented in Table 4-10. For all three reaches, and over two time periods (1976 to 1992 and 1983 to 1992), the probability of at least two exceedences occurring over a three-year period exceeds 99%.

4.2.3 Category of Injury: Injury to Fishery Resources

Chapter 6.0 describes injuries to fishery resources as confirmed by fishkills, *in situ* bioassays, and laboratory toxicity studies that were used to evaluate the effects of hazardous substances on fish mortality, growth, and behavioral avoidance. These laboratory studies were used to establish concentrations of metals which can be applied as "fish injury thresholds" to ambient conditions in the Clark Fork River. The findings of the studies, and the fish injury criteria which they established, are:

- Significant mortality was observed in trout exposed in the laboratory to 8-hour "pulses" of hazardous substances.

- Fifty percent of trout were killed when exposed to metals at concentrations of 1.4 µg/l Cd, 83 µg/l Cu, 0.03 µg/l Pb, and 132 µg/l Zn in 96-hour laboratory toxicity studies.

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[4] It was conservatively assumed that the first-order autocorrelation coefficient is zero. However, it is likely that the coefficient is positive (i.e., a water quality measurement taken on one day is likely to be correlated to water quality conditions on the following day). This simplifying assumption is conservative because positive autocorrelation would tend to cause exceedences to co-occur, increasing the likelihood of successive exceedences.

[5] In other words, an eight-day timeframe would contain two discrete four-day periods. Again, this is a conservative approach.

Table 4-10
Probabilities of at Least Two Chronic Copper Criteria Exceedences Estimated with the Hypergeometric Distribution

Period	Reach	Hits[1]	Misses[1]	%Hits	Probability of ≥2 Exceedences in 3 Years
76-92	Turah Br.	23	21	52.3	>99.9%
	Gold Cr.	24	12	66.7	>99.9%
	Deer Lodge	36	15	70.6	>99.9%
83-92	Turah Br.	20	20	50	>99.7%[2]
	Gold Cr.	21	11	65.6	>99.9%
	Deer Lodge	29	13	69	>99.9%

1 Hits and misses represent observed exceedences and non-exceedences, respectively, during May - June.
2 This value increases to >99.9% when overlapping four-day windows are allowed.

- Brown trout growth was significantly reduced by exposure to 1.1 μg/l Cd, 12 μg/l Cu, 3.2 μg/l Pb, and 50 μg/l Zn in laboratory studies.

- Trout avoided concentrations of 1.2 μg/l Cu and 5.0 μg/l Zn in behavioral avoidance studies (cadmium and lead were at nominal concentrations below analytical detection limits).

Fish injury thresholds are summarized in Table 4-11.

4.2.3.1 Acute Toxicity

The history of the Clark Fork River fishery includes numerous documented fishkills (Chapter 6.0). These fishkills generally have been associated with two kinds of events:

- "Redwater" events, which were common up until 1972
- Storm-related "pulses," which have been documented since 1972.

Before wastewater treatment was upgraded at Anaconda Company's Butte operations in the early 1970s, "redwater" events (redwater referred to the high concentrations of ferric

Table 4-11
Fish Injury Criteria Established by Laboratory Toxicology Studies
(criteria expressed in µg/l)

Response	Cadmium	Copper	Lead	Zinc
Pulse Survival	2	120	3.2	230
Survival	1.4	83	0.03	132
Growth	1.1	12	3.2	50
Avoidance	0.11	1.2	0.32	5

hydroxide which imparted a deep red or yellow color to the water) were a frequent occurrence in the Clark Fork River. These events resulted from releases from Anaconda Company's Butte operations and the Warm Springs Ponds. Although few fishkills were documented in the Clark Fork River during redwater events, the available fish population data indicate that fish populations in the upper Clark Fork River were virtually non-existent until wastewater treatment facilities at the Butte Operations were upgraded in 1972 (Chapter 6.0). Redwater events, which often occurred as far downstream as Missoula, generally ceased by 1972.

Redwater events were sampled by the U.S. EPA in 1970 (U.S. EPA, 1972) (Table 4-12). In the upper Clark Fork River, where fishkills have been most commonly observed (reaches near Warm Springs, Dempsey, and Deer Lodge), dissolved copper concentrations ranged from 20 μg/l to 70 μg/l. Dissolved zinc concentrations, which ranged from 60 μg/l to 1,400 μg/l, were at times greater than the injury criterion established in laboratory pulse experiments.

Since 1972, fishkills in the Clark Fork River have been associated with releases of metals from streamside and floodplain tailings deposits during storm-related runoff events. Fishkills resulting from such releases occurred in the years 1973, 1983, 1984, 1987, 1988, 1989, 1990, and 1991 (see Chapter 6.0, Table 6-1). The mechanism of hazardous substance releases from these deposits involves the formation of soluble metals-bearing salt crusts on the surface of exposed tailings deposits during warmer weather (Montana DHES and CH_2M Hill, 1989a). These salts, which contain high concentrations of copper and zinc, are readily dissolved by rainwater and washed into nearby surface waters. During storm events of sufficient intensity, instream metals concentrations increase substantially as this runoff enters the surface water. Montana DHES and CH_2M Hill (1989a) concluded that "the available evidence at this time points to the visible salts on the tailings deposits as the primary cause of the fishkills."

Table 4-12
Concentrations of Hazardous Substances in the Clark Fork River, 1970
(concentrations in ppb)[1]

Parameter	Date	Pond 3 at Outfall	Warm Springs	Dempsey	Deer Lodge	Tavenner Ranch Bridge	Garrison	Drummond
Total copper	July 14	—	52	400*	1,200*	205	22	—
	August 11	90	80	60	70*	50	70	50
	October 6	1,300*	380*	60	70	460	60	50
	October 7	880	130	100	80	80	70	60
	October 21	19,500*	1,360*	80	70	50	70	70
	October 22	220*	160	70	30	40	30	40
Dissolved copper	July 14	—	—	—	—	—	—	—
	August 11	60	40	40	40*	40	30	40
	October 6	50*	70*	60	50	190	60	40
	October 7	50	40	40	30	40	20	40
	October 21	—	60*	40	20	30	40	40
	October 22	40*	40	30	20	170	30	30
Total zinc	July 14	—	280	960*	4,700*	440	30	—
	August 11	80	400	110	70*	60	40	40
	October 6	4,600*	1,500*	210	180	240	140	90
	October 7	2,800	440	280	—	140	120	100
	October 21	67,500*	4,200*	310	170	160	130	140
	October 22	660*	1,800	340	160	170	90	80
Dissolved zinc	July 14	—	280	110*	110*	90	30	—
	August 11	80	240	70	60*	40	30	20
	October 6	100*	560*	200	—	—	—	—
	October 7	360	320	280	—	140	100	90
	October 21	67,500*	880*	210	140	160	130	110
	October 22	50*	1,400	240	150	140	90	40

* Indicates samples collected where red or yellow water was observed.

1 U.S. EPA, 1972.

Data collected during redwater events and fishkills associated with these pulse releases are presented in Table 4-13. These data demonstrate that during pulse events, surface water concentrations of hazardous substances exceed AWQC by orders of magnitude.

Samples of surface runoff from streamside tailings deposits have been collected from several locations along Silver Bow Creek (Table 4-14). Such runoff characterizes hazardous substance concentrations to which fish could be exposed at the beginning of a storm-generated pulse event. During the Silver Bow Creek Investigation/Warm Springs

Table 4-13
Concentrations of Hazardous Substances in the Clark Fork River (CFR)
During "Redwater" and "Pulse" Events
(concentrations in ppb total recoverable; dissolved concentrations in parentheses)[1]

Date	Sample Collection Location	Event	Cd	Cu	Fe	Pb	Zn
March 10, 1960*	CFR below Warm Springs Ponds	redwater	—	9,000	110,000	—	—
	CFR above East Missoula	redwater	—	3,100	1,100	—	—
May 1, 1968	CFR between Deer Lodge & Garrison	redwater	—	620	19,500	—	4.3
November 20, 1968	CFR near Warm Springs	redwater	—	4,000	95,000	—	32,500
April 10, 1969	CFR at Deer Lodge	redwater	—	1,100	12,500	—	3,600
March 1, 1972	CFR near Warm Springs	redwater	—	820	11,400	—	500
May 27, 1988**	Mill-Willow Bypass	storm event	—	2,480	—	—	3,250
July 12, 1989**	Mill-Willow Bypass	storm event	85	13,300	43,900	30	14,000
	CFR below Warm Springs Creek		6	450	NA	10	800
	CFR at Perkins Lane		3	180	NA	4	120
	CFR near Galen		3	370	NA	2	210
	CFR at Deer Lodge		3 (2)	330 (120)	NA	15 (<1)	560 (230)
July 2, 1990**	Mill-Willow Bypass	storm event	—	5,800	—	—	10,300
August 20, 1991**	Standing water on tailings surface near Galen	storm event	23,000	5,520,000	—	—	8,160,000
Acute criteria at hardness = 200 ppm	—	—	8.6	34.1	None	197.3	210.6

* Water samples collected in association with mortality to caged fish placed instream; no dead native fish observed.
** Water samples collected and analyzed in association with a documented fishkill.
NA Not available.

1 Phillips, 1992.

Table 4-14
Concentrations of Hazardous Substances in Surface Runoff from Streamside Tailings
(concentrations in μg/l total recoverable)

Source	Cd	Cu	Pb	Zn
Colorado Tailings				
Snowmelt runoff March 10, 1989[1]	74	21,100*	87	27,200
Storm event runoff July 8, 1986[2]	928	233,000	161	282,000
Ramsay Flats				
Storm event runoff July 16, 1986[2]	1,250	202,000	3,100	264,000
Several miles above Mill-Willow Bypass				
Simulated storm-event runoff[3]	NM	640,000**	NM	NM

* Indicates acid soluble concentration.
** Indicates dissolved concentration.
NM Not measured.

1 CH_2M Hill and Chen-Northern, 1990.
2 CH_2M Hill, 1987.
3 MDHES and CH_2M Hill, 1989.

Ponds Feasibility Study (MDHES and CH_2M Hill, 1989), a storm event was simulated using sprinklers on a tailings deposit upstream of the Mill-Willow Bypass. The generated runoff contained a dissolved copper concentration of 640,000 μg/l and a total copper concentration of 930,000 μg/l. The feasibility study estimated that 70% of the copper measured was dissolved. The dissolved copper concentration exceeded the copper acute AWQC (18 μg/l) by a factor of more than 35,000, and exceeded the fish pulse survival threshold (120 μg/l) by a factor of more than 5,300. These factors equate to the amount of instream dilution which would be required to reduce the dissolved copper concentration in the runoff to the respective criteria.

4.2.3.2 Chronic Toxicity

The dissolved metals data collected by the U.S. EPA in 1970 indicate that the fish growth and avoidance thresholds for copper were exceeded frequently, if not continuously, in the entire Clark Fork River between Warm Springs and Drummond. The lowest measured dissolved copper concentration (20 μg/l) exceeds the threshold. The zinc growth threshold (50 μg/l) was exceeded in all samples collected from Warm Springs to Deer Lodge, and in almost two-thirds of most samples collected from Tavenner Ranch bridge

to Drummond. The zinc avoidance threshold (5 $\mu g/l$) was exceeded in all samples collected during the survey. The data indicate that conditions during the late summer of 1970 were frequently toxic to fish on the basis of fish injury criteria.

Water quality data collected since the mid-1980s indicate that dissolved metals concentrations at locations over the entire length of the Clark Fork River continue to exceed concentrations that caused avoidance and impaired growth in fish. The three studies which provided dissolved metals data for this assessment were conducted by the United States Geological Survey (USGS), the Montana Bureau of Mines and Geology (MBMG) and the Natural Resource Damage Program (NRDP). Samples were collected from the upper (Perkins Lane/Galen) to the lower (Turah) reaches of the Clark Fork River.

The USGS (Lambing, 1991; STORET) collected dissolved metals data at three locations: Galen (1988-1992), Deer Lodge (1985-1992) and Turah (1985-1992). Samples were collected approximately seven times per year, with more intensive sampling during high flows and periods of runoff. In 1991, the MBMG conducted continuous sampling during post-runoff and summer low-flow periods for 54 days at Perkins Lane (July 9 - August 31) and for 103 days at Deer Lodge (May 21 - August 31). Most samples at each site were analyzed for dissolved copper and zinc. The frequency of sample analyses ranged from 2 to 12 per day, but averaged one analysis every 7 hours at Perkins Lane, and one analysis every 6 hours at Deer Lodge. The NRDP collected dissolved metals samples at five locations from the upper, middle, and lower river on six dates during the runoff and early post-runoff period in 1992.

Ranges and means of dissolved copper and zinc concentrations, and the percentage of samples exceeding the growth and avoidance thresholds are summarized in Tables 4-15 and 4-16. The data indicate that the avoidance thresholds for copper and zinc were exceeded in most, if not all, samples collected over the entire length of the Clark Fork River. Growth thresholds are exceeded less frequently than the avoidance thresholds, and tend to be exceeded less frequently with increasing distance downstream. Mean dissolved copper concentrations exceeded avoidance thresholds at all locations, and in some cases exceeded growth thresholds in the upper Clark Fork River. Mean zinc concentrations in the Clark Fork River (Perkins Lane/Galen and Deer Lodge) always exceeded the zinc avoidance threshold.

Figures 4-7 through 4-9 illustrate dissolved copper and zinc data for stations at Galen, Deer Lodge, and Turah, including USGS data, data collected by the U.S. EPA in 1970 at Deer Lodge, and miscellaneous dissolved metals data collected during other investigations. Dissolved metals concentrations are compared to the fish growth and avoidance thresholds (indicated by dashed lines). These comparisons indicate that concentrations of copper and zinc in the Clark Fork River are sufficient to cause injury to fish.

Table 4-15
Concentrations of Dissolved Copper in the Clark Fork River Compared to Fish Injury Thresholds (concentrations in $\mu g/l$)[*]

Location	Concentration Range	Mean	Number of Samples	Percentage Exceeding Growth (12 $\mu g/l$)	Percentage Exceeding Avoidance (1.2 $\mu g/l$)
Perkins Lane/Galen					
USGS	3 - 50	13	25	32	100
MBMG	5 - 19	10	178	12	96
RI/FS	<DL - 10	NC	15	NC	NC
Duaime *et al.*, 1990a	2 - 22	13	7	71	100
Duaime *et al.*, 1990b	8 - 63	18	42	71	100
Deer Lodge					
USGS	4 - 120	15	42	33	100
MBMG	4 - 28	12	408	2	98
NRDP	6 - 10	8	6	0	100
Gold Creek					
NRDP	3 - 6	4	6	0	100
Bearmouth					
NRDP	3 - 5	4	6	0	100
Beavertail Hill					
NRDP	2 - 4	4	6	0	100
Turah					
USGS	2 - 25	6	41	7	98
NRDP	<1 - 2	2	6	0	83

* <DL = less than the detection limit; NC = not calculated; USGS = United States Geological Survey; MBMG = Montana Bureau of Mines and Geology; NRDP = Natural Resource Damage Program; RI/FS = Silver Bow Creek Remedial Investigation/Feasibility Study.

Table 4-16
Concentrations of Dissolved Zinc in the Clark Fork River Compared to Fish Injury Thresholds (concentrations in μg/l)*

Location	Concentration Range	Concentration Mean	Number of Samples	Percentage Exceeding Growth (50 μg/l)	Percentage Exceeding Avoidance (5 μg/l)
Perkins Lane/Galen					
USGS	3 - 110	26	25	14	100
MBMG	5 - 36	9	178	0	100
RI/FS	<DL - 120	49	15	NC	NC
Duaime *et al.*, 1990a	8 - 46	25	7	0	100
Duaime *et al.*, 1990b	6 - 382	48	42	19	100
Deer Lodge					
USGS	3 - 230	22	42	40	100
MBMG	2 - 77	13	408	1	96
NRDP	4 - 13	9	6	0	83
Gold Creek					
NRDP	2 - 7	3	6	0	17
Bearmouth					
NRDP	3 - 6	4	6	0	13
Beavertail Hill					
NRDP	2 - 4	2	6	0	0
Turah					
USGS	<3 - 39	10	41	0	68
NRDP	<1 - 6	2	6	0	13

* <DL = less than the detection limit; NC = not calculated; USGS = United States Geological Survey; MBMG = Montana Bureau of Mines and Geology; NRDP = Natural Resource Damage Program; RI/FS = Silver Bow Creek Remedial Investigation/Feasibility Study.

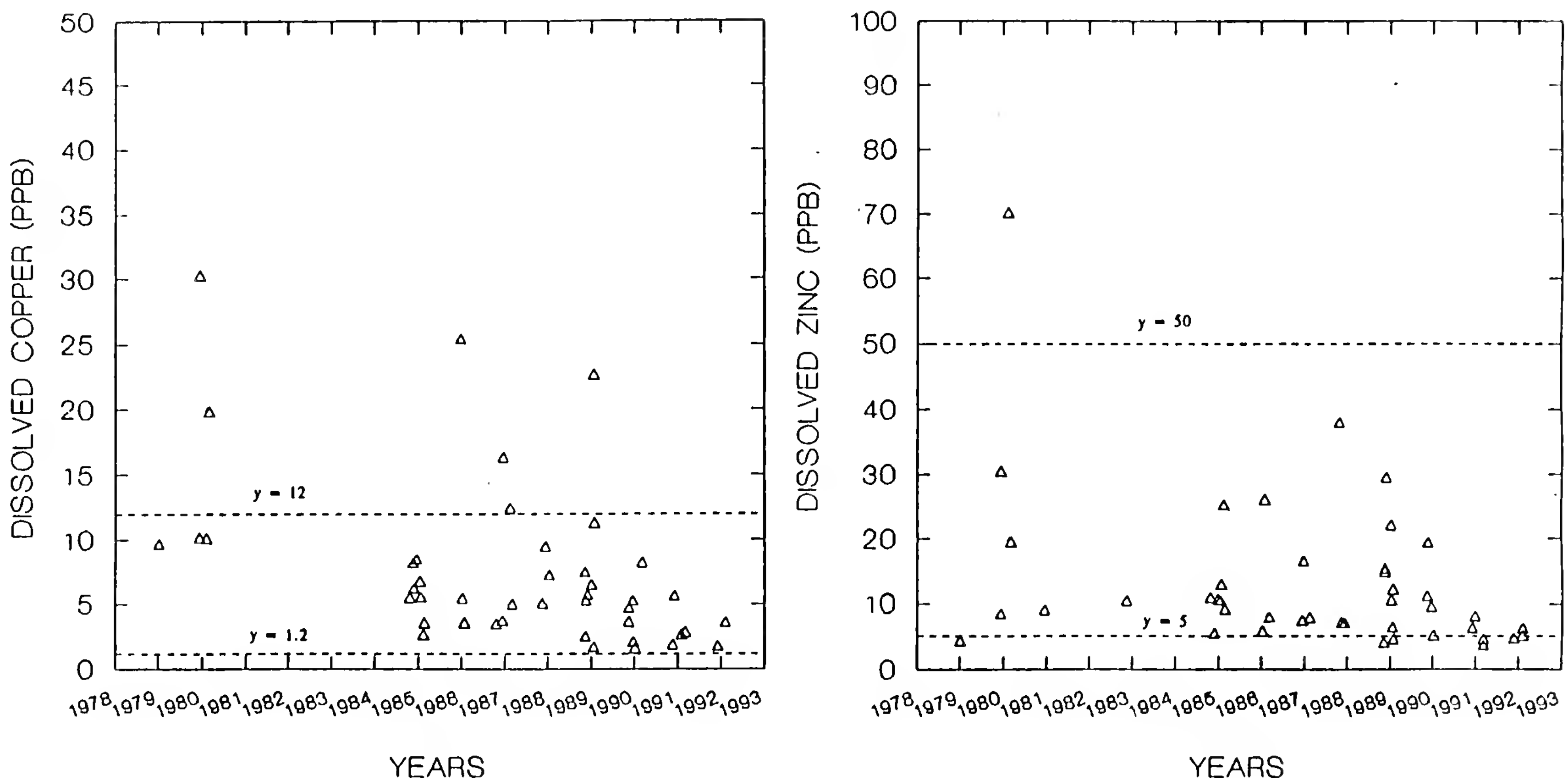

Figure 4-7. Concentrations of Dissolved Copper and Zinc (μg/l) in the Lower Clark Fork River, Reach CFR1 (Turah). Dashed lines represent fish growth and avoidance thresholds.

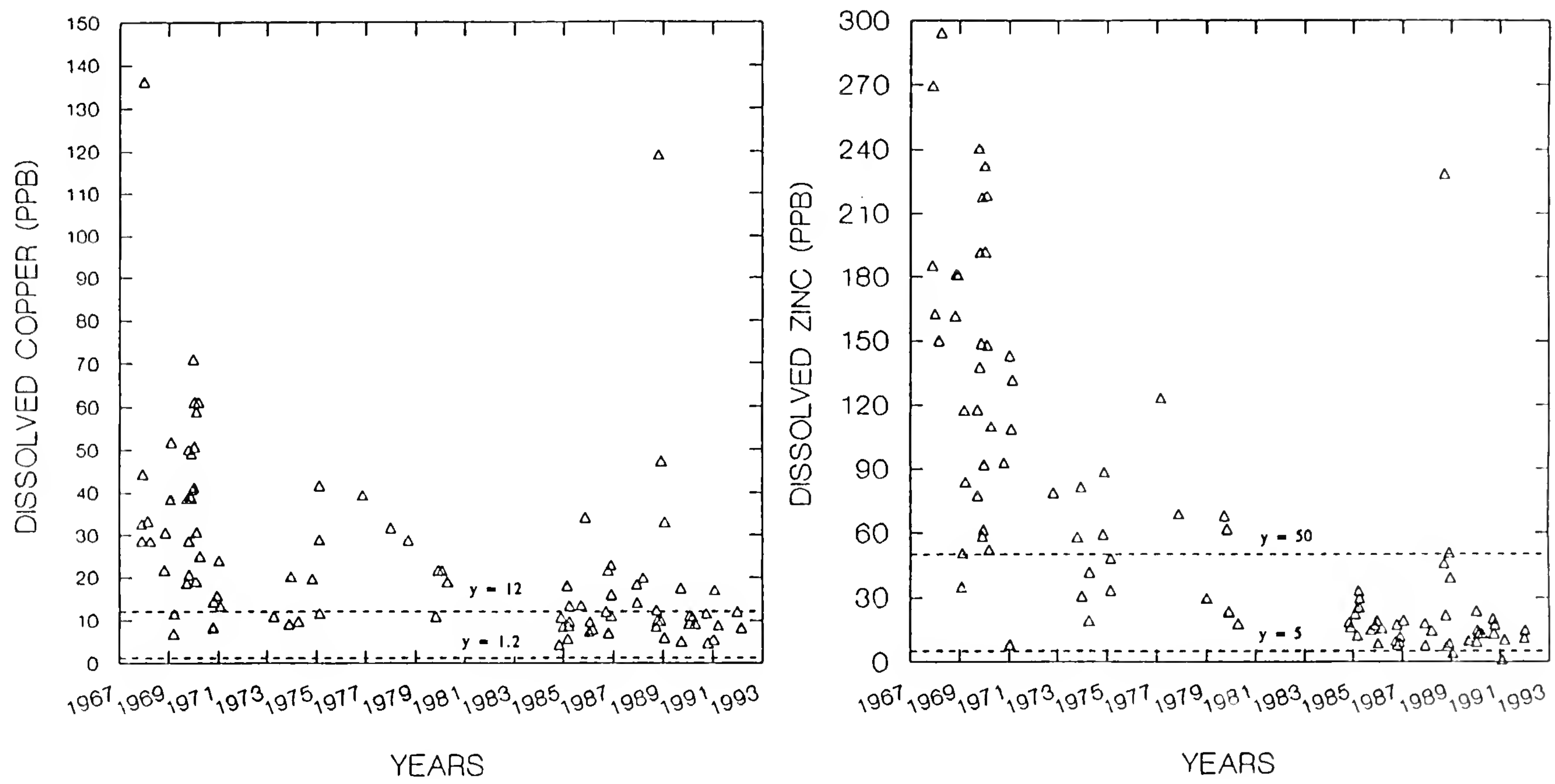

Figure 4-8. Concentrations of Dissolved Copper and Zinc (µg/l) in the Middle Clark Fork River, Reach CFR6B (Deer Lodge). Dashed lines represent fish growth and avoidance thresholds.

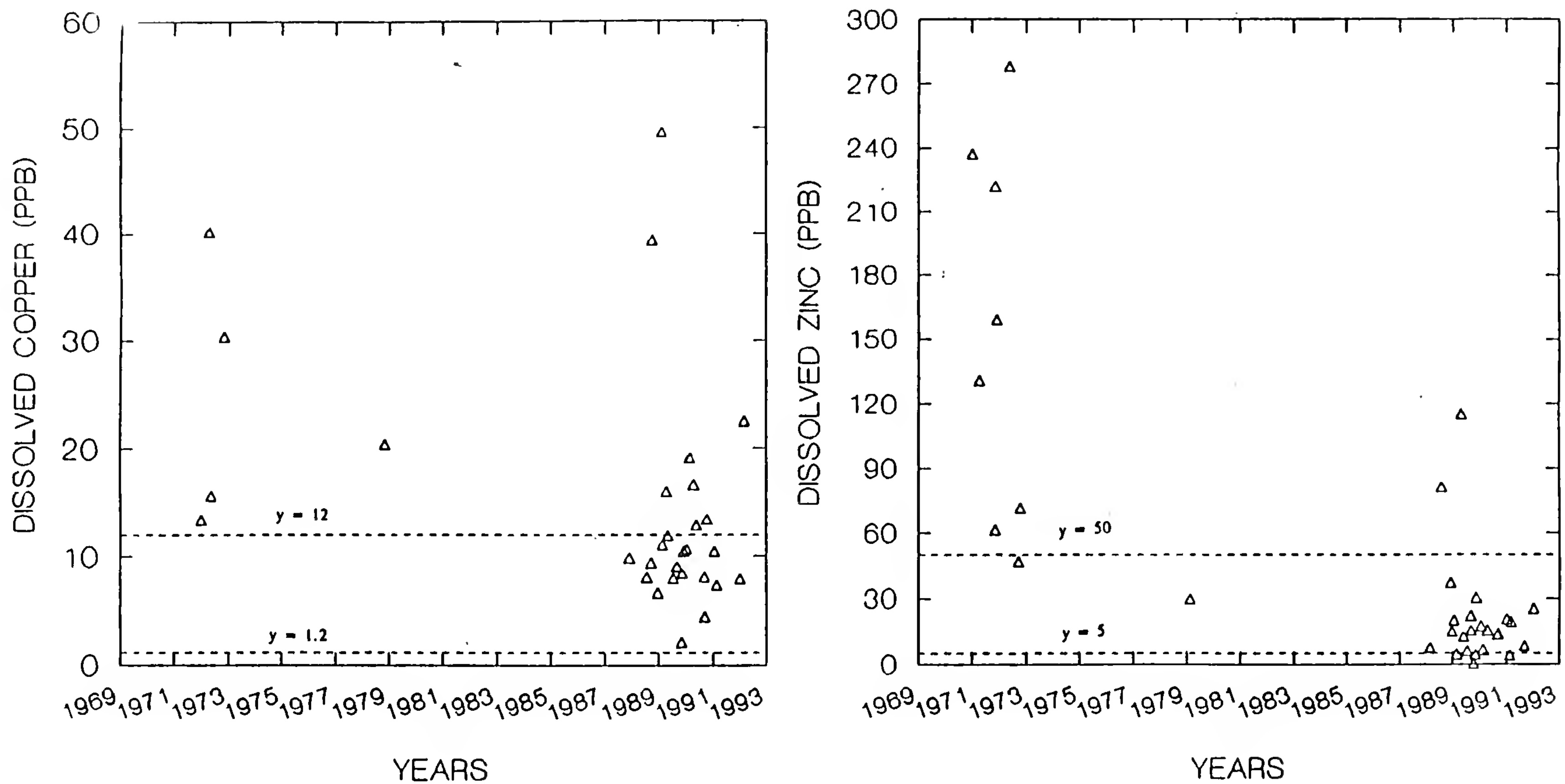

Figure 4-9. **Concentrations of Dissolved Copper and Zinc (µg/l) in the Upper Clark Fork River, Reach CFR6D (Galen).** Dashed lines represent fish growth and avoidance thresholds.

4.2.4 Baseline Comparison

Historical data to assess pre-release baseline conditions in Silver Bow Creek and the Clark Fork River are not available because releases have occurred since the late 1800s (and hence pre-date water quality sampling). For the purposes of baseline determination, Blacktail Creek, the major upstream tributary to Silver Bow Creek, was deemed representative of pre-release conditions [43 CFR § 11.72(d)(2)]. For the Clark Fork River, three principal tributaries, Rock Creek, the Little Blackfoot River, and Warm Springs Creek, were selected to represent baseline conditions. Comparisons of conditions in Silver Bow Creek and the Clark Fork River relative to baseline are presented below.

4.2.4.1 Silver Bow Creek

Pre-release concentrations of hazardous substances in Silver Bow Creek can be characterized by the water quality of other regional streams, particularly those which drain areas geologically similar to the upper Silver Bow Creek drainage. Three Boulder Batholith streams (upper Silver Bow Creek, Yankee Doodle Creek, and Blacktail Creek) which presently are, or at one time were, tributaries of Silver Bow Creek were sampled in 1992 by the Natural Resource Damage Program (NRDP) (see Appendix A). These streams are relatively unaffected by mining impacts and are therefore useful in characterizing hazardous substance concentrations which may have existed in Silver Bow Creek prior to the releases of hazardous substances. Cadmium, copper, lead and zinc concentrations (U.S. EPA total recoverable) are plotted in Figure 4-10. The data indicate that concentrations of these metals are significantly elevated in Silver Bow Creek relative to other Boulder Batholith streams.

Upper Silver Bow Creek and Yankee Doodle Creek have been bisected by the Yankee Doodle Tailings and the Berkeley Pit, and are no longer tributaries of Silver Bow Creek. Blacktail Creek is today the major headwater tributary to Silver Bow Creek, and was therefore selected as the appropriate baseline for Silver Bow Creek. Hazardous substance concentrations were characterized during the Silver Bow Creek RI (MultiTech, 1987e). Fifteen samples were collected between November 1984 and July 1985. The Blacktail Creek sampling location (just above the Metro Storm Drain) makes it uncertain as to whether the stream is entirely free from effects of releases of hazardous substances. Therefore, the baseline comparison to Silver Bow Creek is conservative. Plots comparing hazardous substance concentrations in Blacktail Creek to Silver Bow Creek (Figure 4-11) illustrate that concentrations of copper and zinc in Silver Bow Creek are significantly greater than in Blacktail Creek. As shown in Figure 4-11 and Table 4-17, concentrations of copper and zinc in Silver Bow Creek significantly exceeded baseline conditions at all

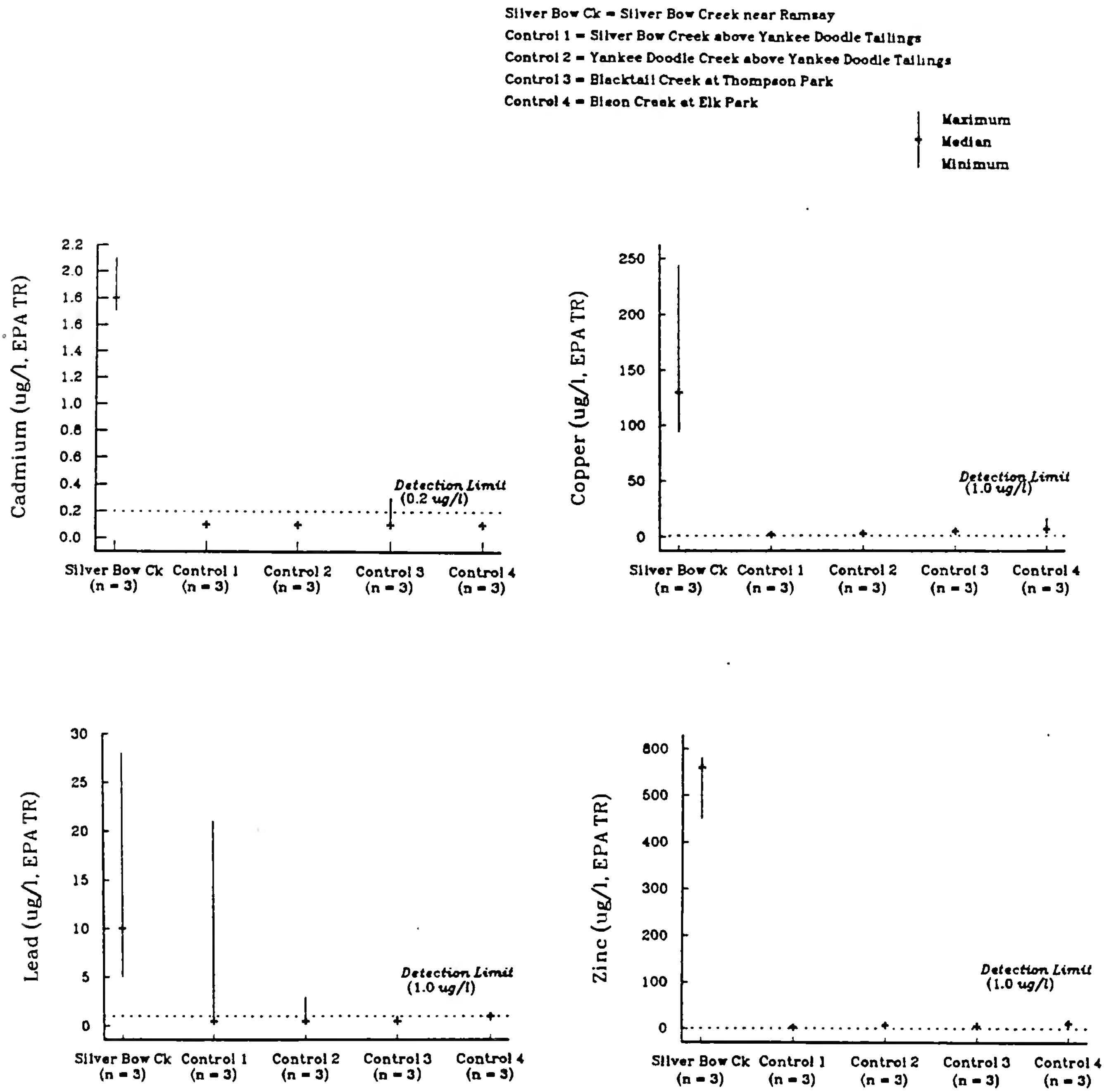

Figure 4-10. Concentrations of Hazardous Substances in Silver Bow Creek Headwater Streams (Upper Silver Bow Creek, Yankee Doodle Creek, and Blacktail Creek) and Fish Population Assessment Control Stream (Bison Creek).

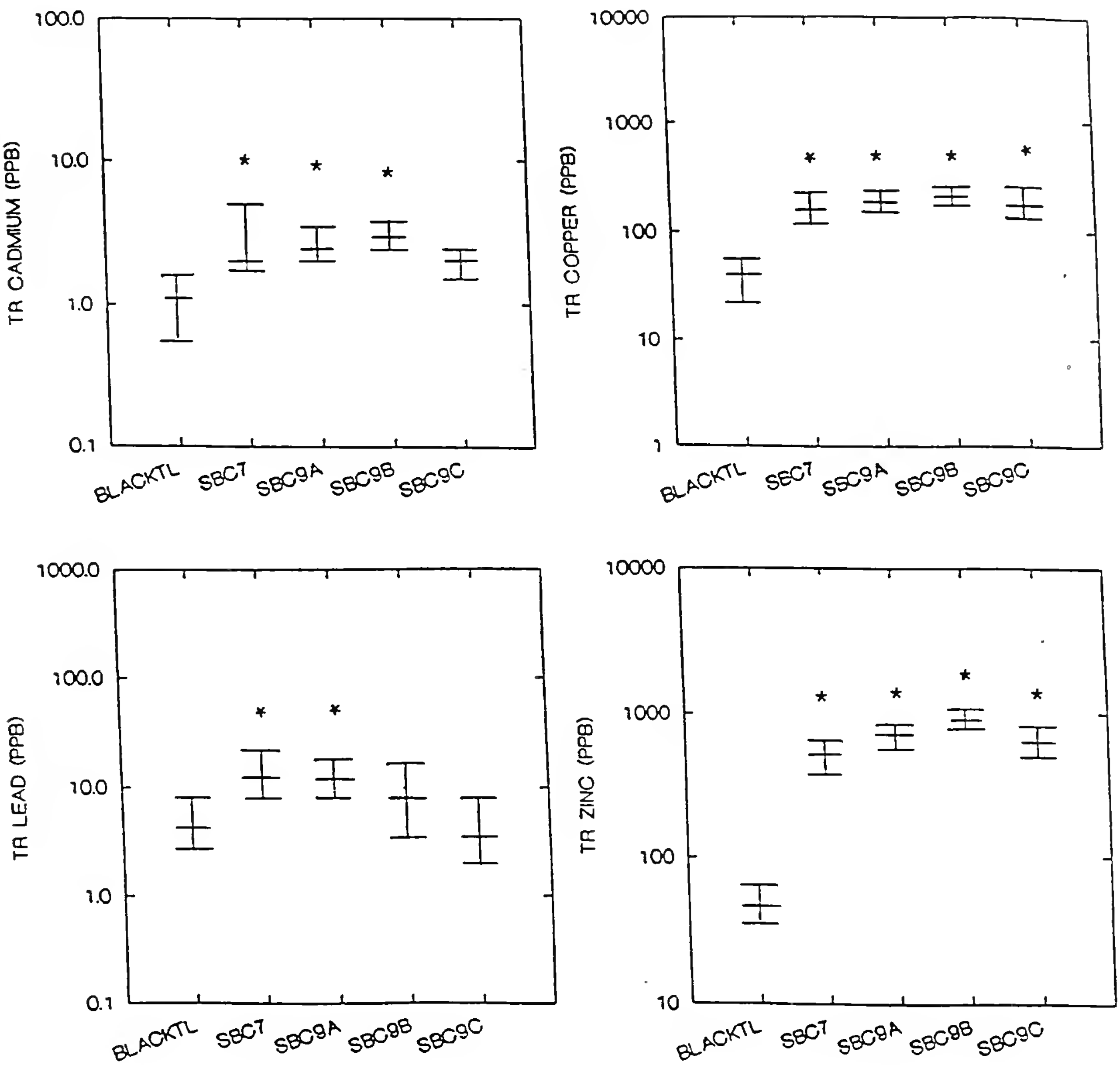

Figure 4-11. Silver Bow Creek (Reaches SBC7 - SBC9C) and Blacktail Creek (BLACKTL) Baseline Comparison for Cadmium, Copper, Lead, and Zinc. (Median and Interquartile Range (25th, 75th percentiles) of Total Recoverable Concentrations, in ppb; * indicates significantly greater concentration in impact reach than in baseline, based on two-sample randomization test.)

Table 4-17
Two-Sample Randomization Test (Manly, 1991) Comparing Hazardous Substance Concentrations in Clark Fork River and Silver Bow Creek to Baseline Conditions (mean difference concentration in ppb)[1,2]

Impact Reach/Baseline	Cadmium Mean Difference	Cadmium p-value	Copper Mean Difference	Copper p-value	Lead Mean Difference	Lead p-value	Zinc Mean Difference	Zinc p-value
SBC7/ Blacktail Creek	1.38	.0172*	175.16	.0002*	12.44	.0220*	544.16	.0002*
SBC8/ Blacktail Creek	NC	NC	NC	NC	NC	NC	NC	NC
SBC9A/ Blacktail Creek	1.11	.0102*	201.93	.0002*	7.35	.0450*	724.72	.0002*
SBC9B/ Blacktail Creek	1.44	.0004*	182.48	.0002*	2.39	.3280	912.07	.0002*
SBC9C/ Blacktail Creek	1.76	.2464	156.76	.0002*	-.352*	.1900	606.11	.0002*
CFR1/ Rock Creek	.08	.2482	61.66	.0002*	4.00	.0066*	113.09	.0002*
CFR2/ L. Blackfoot River	-.70[3]	.0002	17.22	.0002*	-.81[4]	.2842	16.05	.0084*
CFR3/ L. Blackfoot River	NC	NC	8.30	.1118	NC	NC	6.23	.3036
CFR4/ L. Blackfoot River	-.73[3]	.0002	19.52	.0002*	-2.03[4]	.0290	11.67	.0308*
CFR5/ L. Blackfoot River	NC	NC	NC	NC	NC	NC	NC	NC
CFR6A/ Warm Springs Creek	.06	.0548	26.48	.0002*	3.01	.0002*	41.11	.0002*
CFR6B/ Warm Springs Creek	.03	.1708	22.73	.0002*	2.38	.0002*	43.02	.0002*
CFR6C/ Warm Springs Creek	.01	.3964	15.91	.0002*	1.44	.0002*	31.56	.0002*
CFR6D/ Warm Springs Creek	NC	NC	4.91	.0774	NC	NC	0.49	.3628
CFR6E/ Warm Springs Creek	.09	.1010	14.39	.0002*	2.24	.0042*	45.67	.0002*
Pond 2 Disch./ Warm Springs Creek	.11	.0212*	19.18	.0002*	3.76	.0002*	61.15	.0002*

[1] NC = not calculated, no data for impact reaches.
[2] Mean difference: positive value indicates higher concentration in impact reach, negative value indicates higher concentration in baseline.
[3] Negative value due to higher analytical detection limit in baseline data.
[4] Negative value may be partly due to stronger sample digestion methods used in baseline data.
* Indicates significantly greater concentration in impact (Clark Fork River and Silver Bow Creek) at $\alpha = 5\%$.

sites. Concentrations of cadmium exceeded baseline at SBC7, SBC9A, and SBC9B, and concentrations of lead exceeded baseline and SBC7 and SBC9A.[6]

4.2.4.2 Clark Fork River

Baseline conditions in the upper, middle, and lower reaches of the Clark Fork River (respectively, Warm Springs Ponds to Little Blackfoot River, Little Blackfoot River to Rock Creek, Rock Creek to Milltown) were assessed using three principal tributary streams: Warm Springs Creek (control for upper reach), Little Blackfoot River (control for middle reach), and Rock Creek (control for lower reach).

Plots comparing concentrations of hazardous substances in control streams (Warm Springs Creek, Little Blackfoot River, and Rock Creek) with matching reaches of the Clark Fork River are presented in Figures 4-12, 4-13, and 4-14.[7] As shown in these figures and in Table 4-17, concentrations of copper and zinc were significantly greater than baseline at all but two Clark Fork River sites (CFR3 and CFR6D). Lead concentrations were significantly greater than baseline at CFR1, CFR6A-C, and CFR6E. Figures 4-15 and 4-16 provide a basin-wide perspective of contamination by copper and zinc. Plots of copper and zinc concentrations for all Silver Bow Creek and Clark Fork River reaches are compared to one reference stream, Warm Springs Creek. Concentrations in the Warm Springs Pond 2 discharge are also plotted. The plots demonstrate that contamination of the surface water resource is significant at even the furthest downstream reach, CFR1.

4.2.5 Committed Use

The DOI NRDA regulations provide that there is an injury to surface water if the concentrations and duration of substances are in excess of applicable water quality criteria in surface water that before the release met the criteria and has a "committed use" as a habitat for aquatic life, water supply or recreation. 43 CFR § 11.62 (b)(1)(iii). A "committed use" is defined as either a current public use or a planned public use for which there is a documented legal, administrative, budgetary, or financial commitment

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[6] Although comparisons were not made for SBC8 because no data were available, the fact that sites both up- and downstream exceeded baseline indicates the almost certainty that SBC8 would exceed baseline as well.

[7] For the baseline comparison, values below the analytical detection limit were set at the detection limit. This approach conservatively treats non-detects from both the impact and baseline streams equally (when the likelihood is that the non-detects in the injured resource represent higher real concentrations than the non-detects in the baseline).

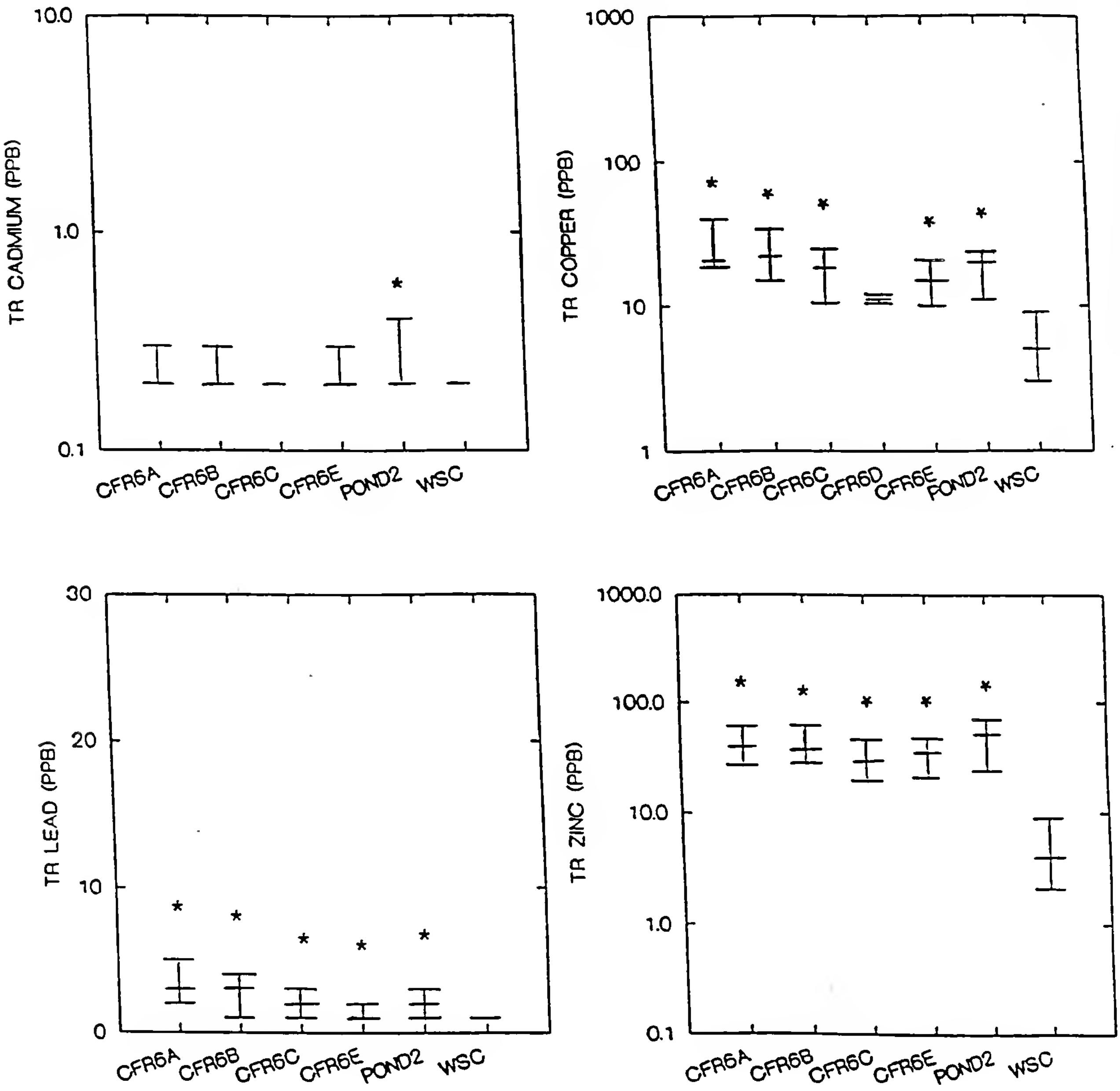

Figure 4-12. Upper Clark Fork River (Reaches CFR6A - CFR6E) and Warm Springs Creek (WSC) Baseline Comparison for Cadmium, Copper, Lead, and Zinc. (Median and Interquartile Range of Total Recoverable Concentrations, in ppb; * indicates significantly greater concentrations in impact reach than in baseline, based on two-sample randomization test.)

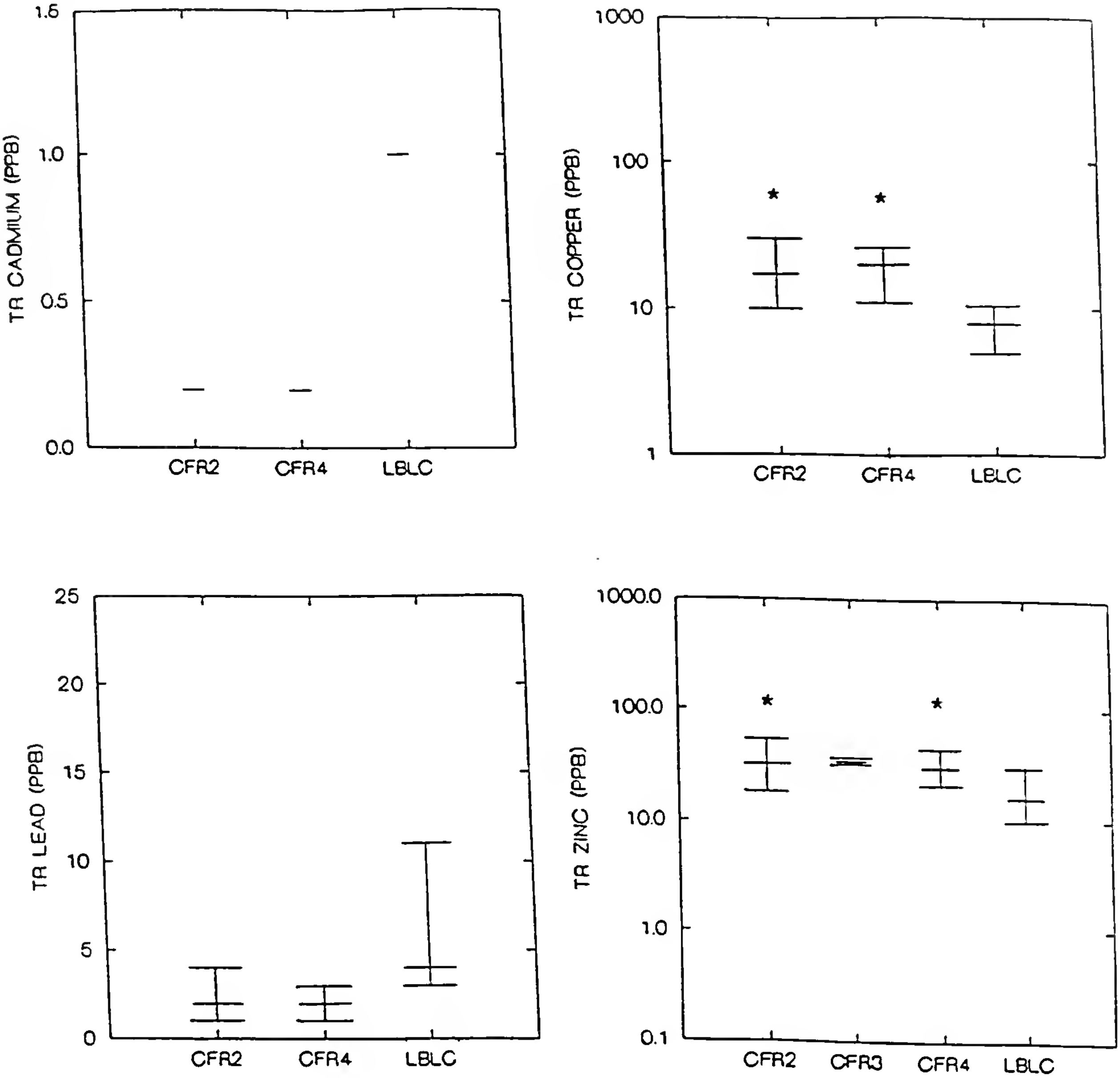

Figure 4-13. Middle Clark Fork River (Reaches CFR2 - CFR5) and Little Blackfoot River (LBLC) Baseline Comparison for Cadmium, Copper, Lead, and Zinc. (Median and Interquartile Range of Total Recoverable Concentrations, in ppb; * indicates significantly greater concentration in impact reach than in baseline, based on two-sample randomization test.)

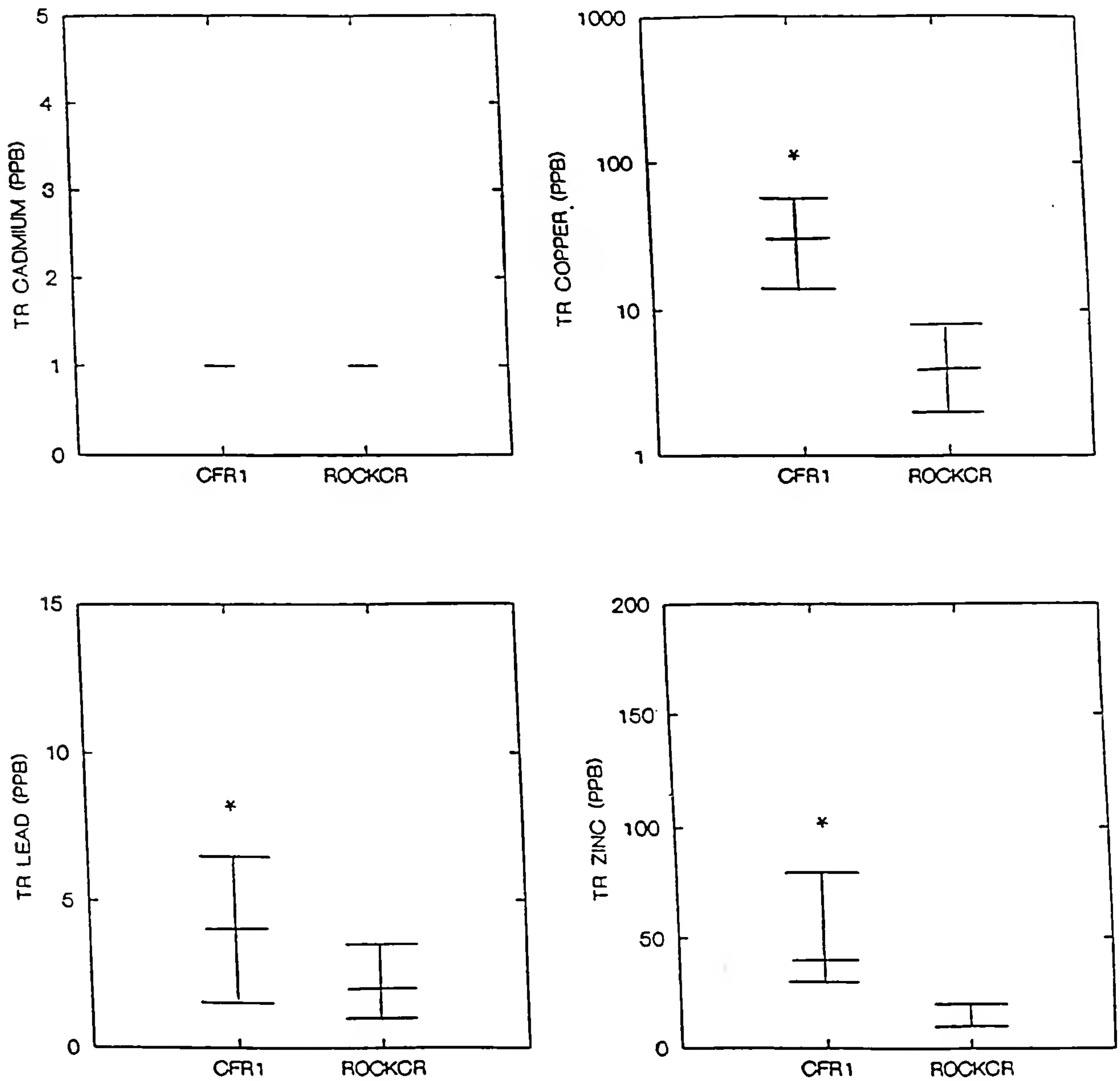

Figure 4-14. Lower Clark Fork River (Reach CFR1) and Rock Creek (ROCKCR) Baseline Comparison for Cadmium, Copper, Lead, and Zinc. (Median and Interquartile Range of Total Recoverable Concentrations, in ppb; * indicates significantly greater concentration in impact reach than in baseline, based on two-sample randomization test.)

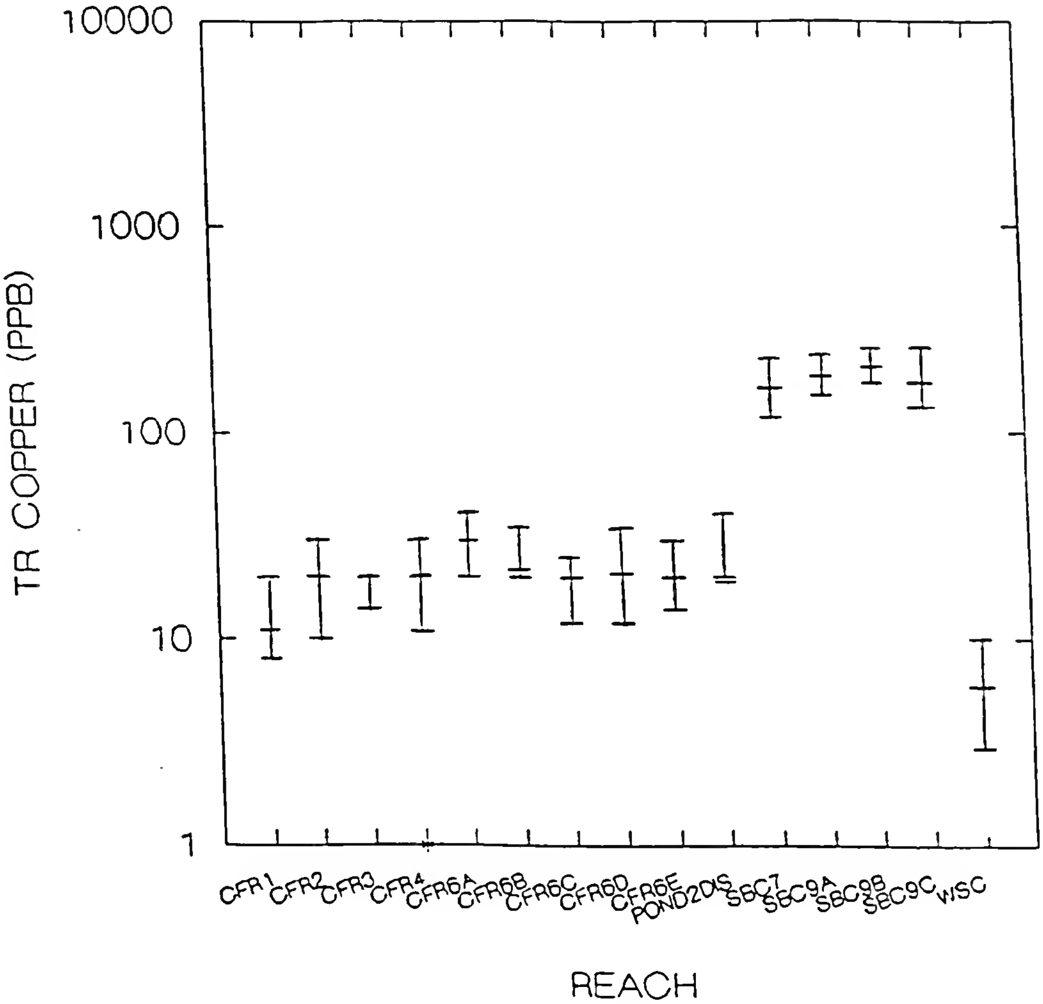

Figure 4-15. Copper in Silver Bow Creek, the Clark Fork River, Warm Springs Pond 2 Discharge, and Warm Springs Creek (1985-1992). (Median and Interquartile Range of Total Recoverable Concentrations, in ppb.)

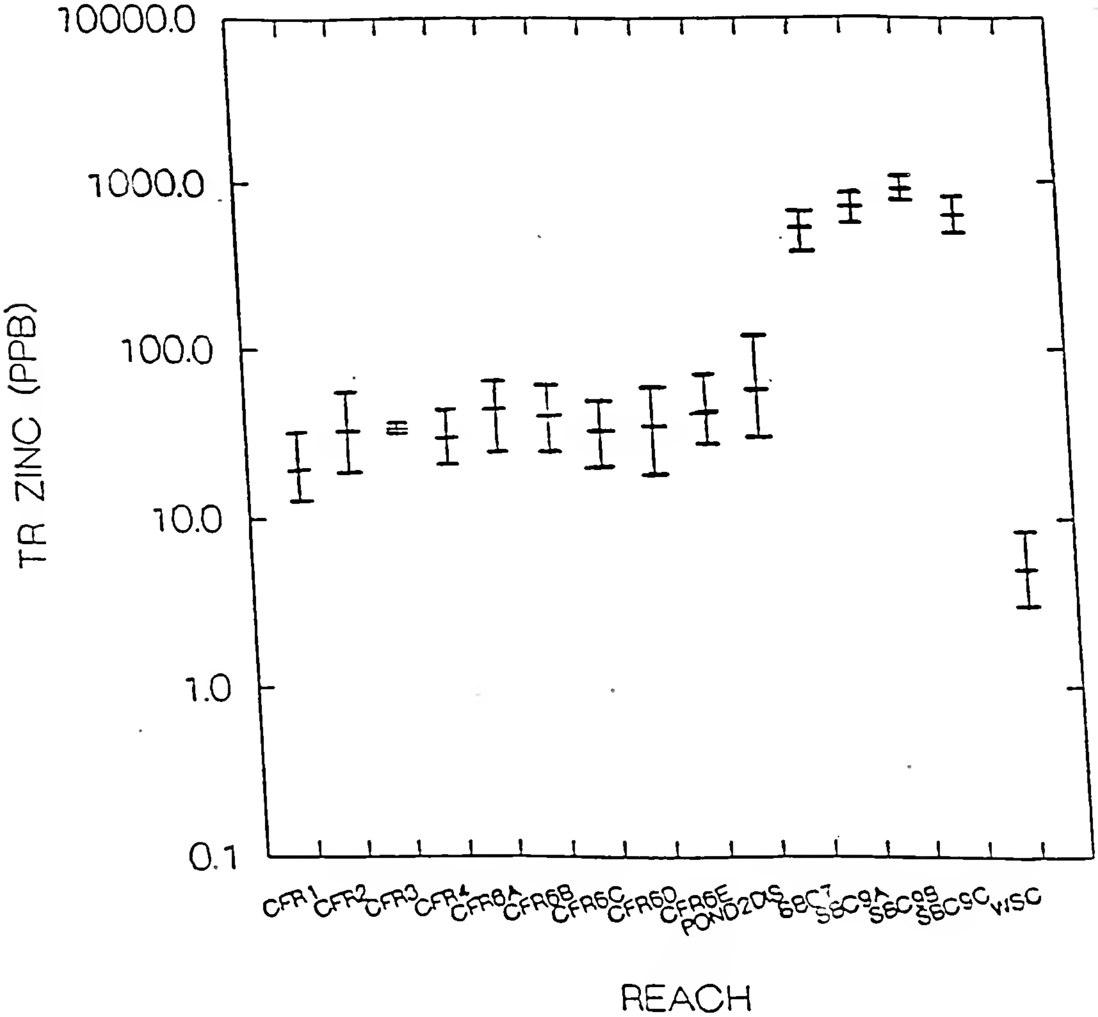

Figure 4-16. Zinc in Silver Bow Creek, the Clark Fork River, Warm Springs Pond 2 Discharge, and Warm Springs Creek (1985-1992). (Median and Interquartile Range of Total Recoverable Concentrations, in ppb.)

before the release of a hazardous substance is detected. [43 CFR § 11.14(h)]. In spite of the injuries resulting from releases of hazardous substances, the Clark Fork River still has current public uses as a habitat for aquatic life, water supply (irrigation), and recreation. The public use of Silver Bow Creek has been severely impacted by the release of hazardous substances. Nevertheless, Silver Bow Creek also has current public uses as a habitat for aquatic life (e.g., macroinvertebrates), water supply (e.g., irrigation), and is frequently used for recreational purposes, as reported in RI/FS documents. Additionally, while it is true that Silver Bow Creek currently does not support fish, as demonstrated not only by this report, but by comparison of Silver Bow Creek with other rivers and streams in southwestern Montana, there would be fish in the creek were it not for the presence of hazardous substances resulting from mining and mineral processing activities in the Butte area. These past, present and future uses of the Clark Fork River and Silver Bow Creek have been documented by various statutory, regulatory, administrative, budgetary, and/or financial commitments by the State. This includes the establishment of applicable surface water quality standards by the Montana Department of Health and Environmental Services.

4.3 INJURY QUANTIFICATION

4.3.1 Silver Bow Creek

Virtually all samples collected from Silver Bow Creek have exceeded both copper and zinc acute and chronic AWQC. Exceedences of greater than 100 times the chronic criterion have been documented for copper. The Silver Bow Creek surface water resource thus is injured for its entire length from Butte to Warm Springs Ponds, a distance of approximately 40 kilometers (24 miles).

The volume of injured surface water, based on records for the USGS station located below the Colorado Tailings, averaged 16,291 acre-feet per water year for the years 1984-1990. Annual mean flow is approximately 23 cfs near Lower Area I and approximately 45 cfs near Opportunity (Canonie, 1992). Therefore, the volume of injured surface water in the lower end of Silver Bow Creek is approximately twice the volume discharged at the Colorado Tailings, or approximately 32,580 acre-feet per water year (Table 4-18).

4.3.2 Clark Fork River

As described previously, copper concentrations have exceeded both acute and chronic AWQC at all sites in the Clark Fork River. In addition, exceedences of chronic AWQC have been observed for zinc and lead. Therefore, the Clark Fork River is continuously injured from its headwaters to Milltown Reservoir, a distance of approximately 120 miles.

Table 4-18
Volume of Surface Water Discharged at USGS Stations on Silver Bow Creek (SBC) and the Clark Fork River (CFR)
(units in acre-feet per water year [w] and acre-feet per calendar year [c])

Station Number	Location (Reach)	Period of Record	Minimum	Mean	Maximum
12323250	SBC below Blacktail Creek (SBC9B)	1983-1991	13,650 (w) 14,770 (c)	16,291 (w) 16,463 (c)	20,610 (w) 20,270 (c)
12323750	CFR at Warm Springs (CFR6E)	1973-1979	61,630 (w) 57,590 (c)	105,790 (w) 109,230 (c)	165,200 (w) 178,300 (c)
12323800	CFR at Galen (CFR6D)	1989-1991	67,640 (w) 65,710 (c)	69,810 (w) 69,080 (c)	73,260 (w) 72,450 (c)
12324200	CFR at Deer Lodge (CFR6B)	1979-1991	112,300 (w) 106,800 (c)	199,520 (w) 203,170 (c)	316,100 (w) 326,200 (c)
12323680	CFR at Gold Creek (CFR4)	1978-1991	193,700 (w) 187,700 (c)	399,840 (w) 408,490 (c)	622,500 (w) 636,500 (c)
12331600	CFR at Drummond (CFR3)	1973-1983	289,900 (w) 269,100 (c)	644,000 (w) 650,940 (c)	1,009,000 (w) 1,074,000 (c)
12331900	CFR at Clinton (CFR1)	1980-1990	301,400 (w) 296,000 (c)	602,390 (w) 616,070 (c)	895,400 (w) 917,700 (c)
12334500	CFR at Turah (CFR1)	1985-1991	596,600 (w) 565,800 (c)	773,430 (w) 768,130 (c)	1,048,000 (w) 1,058,000 (c)

Continuous USGS discharge records exist for seven stations on the Clark Fork River for varying periods of record. Volumes of injured surface water, in acre-feet per water year, averaged 199,520 at Deer Lodge (1979-1991); 399,840 at Gold Creek (1978-1991); and 773,430 at Turah (1985-1991) (Table 4-18).

4.3.3 Temporal Extent of Injury

4.3.3.1 Silver Bow Creek

The Silver Bow Creek system has been contaminated by over 100 years of mining and smelting activities within the basin (MultiTech, 1987a). Hazardous substances currently occur at concentrations which result in continuous injury to the entire resource. Data

suggest that copper and zinc concentrations have continuously exceeded AWQC for at least 23 years; it is likely that Silver Bow Creek has been injured for over 100 years.

4.3.3.2 Clark Fork River

Copper AWQC and fish injury thresholds have been, and continue to be, exceeded virtually every year in all reaches of the Clark Fork River. As with Silver Bow Creek, data suggest that these exceedences have occurred for at least 23 years; it is likely that the Clark Fork River has been injured for over 100 years.

4.3.4 Ability of Resource to Recover

4.3.4.1 Silver Bow Creek

Natural recovery of Silver Bow Creek will proceed extremely slowly. The Silver Bow Creek floodplain contains large amounts of tailings, wastes, and contaminated soils and will release hazardous substances to the Creek for many years. Contaminated groundwater continues to discharge hazardous substances, including metals, to Silver Bow Creek near Area I (Section 4.5.2.2). Hazardous substances in sediments of Silver Bow Creek are not naturally degraded or decomposed.

Natural recovery of Silver Bow Creek is essentially inestimable. U.S. EPA (1992) stated "the recovery period [for the aquatic ecosystem in the Area I] has virtually been eliminated."

4.3.4.2 Clark Fork River

Natural recovery of sediments of the Clark Fork River will require many hundreds if not thousands of years, for the following reasons:

- Hazardous substances continue to be released to the Clark Fork River from Silver Bow Creek and Warm Springs Ponds. The Warm Springs Pond 2 discharge continues to release metals to the Clark Fork River via continuous direct discharge to the lower Silver Bow Creek channel. Re-releases of metals, in concentrations which exceed AWQC, have been reported as recently as 1993 in ARCO discharge monitoring reports.

- Large amounts of hazardous substances continue to be released to the Clark Fork River from streamside tailings and contaminated soils deposited along floodplains and in bed sediments of the Clark Fork River. The more

than 2,000,000 cubic meters of tailings and waste material that have been deposited along the Clark Fork River floodplains will continue to release hazardous substances to the Clark Fork River for many years to come.

- The hazardous substances released to the Clark Fork River are not degraded or decomposed biologically and remain persistent in the environment for long periods of time.

4.4 SURFACE WATER CONCENTRATIONS OF HAZARDOUS SUBSTANCES AT FISH POPULATION SITES

Fish population studies were conducted at sites in Silver Bow Creek and the Clark Fork River, and on matching control streams (Figure 4-17) (see Chapter 6.0). In order to control for variables associated with fish population measurements, sites were matched based on a hierarchial classification which included ecological, geological, geomorphic, and hydrologic characteristics (see Chapter 6.0).

Water samples were collected in April and May, 1992 by the Montana NRDP from matched impact and control sites, and were analyzed for cadmium, copper, lead, and zinc (U.S. EPA total recoverable and dissolved concentrations) (see Appendix A). These data were collected to characterize the surface water contamination of impact (Silver Bow Creek and Clark Fork River) sites relative to the control sites. Metals concentrations were compared using two-sample randomization tests (Manly, 1991). Tables 4-19 and 4-20 summarize results for comparisons of U.S. EPA total recoverable concentrations (cadmium, copper, lead, and zinc) and dissolved concentrations (copper and zinc only). At the $\alpha=5\%$ level, U.S. EPA total recoverable concentrations of copper, lead, and zinc were significantly greater at all impact sites relative to the paired control sites. Cadmium was significantly higher in Silver Bow Creek than in the paired Bison Creek match site. Dissolved copper was significantly greater in all impact sites than in control sites. Dissolved zinc was significantly greater in Silver Bow Creek and the Clark Fork River at Deer Lodge. Dissolved concentrations of cadmium and lead were not compared because in most cases, concentrations were not detectable.

Concentrations of hazardous substances in Clark Fork River and control fishery sites are plotted in Figure 4-18 (see Figure 4-10 for hazardous substance concentrations in the Silver Bow Creek fishery site and its control, Bison Creek).

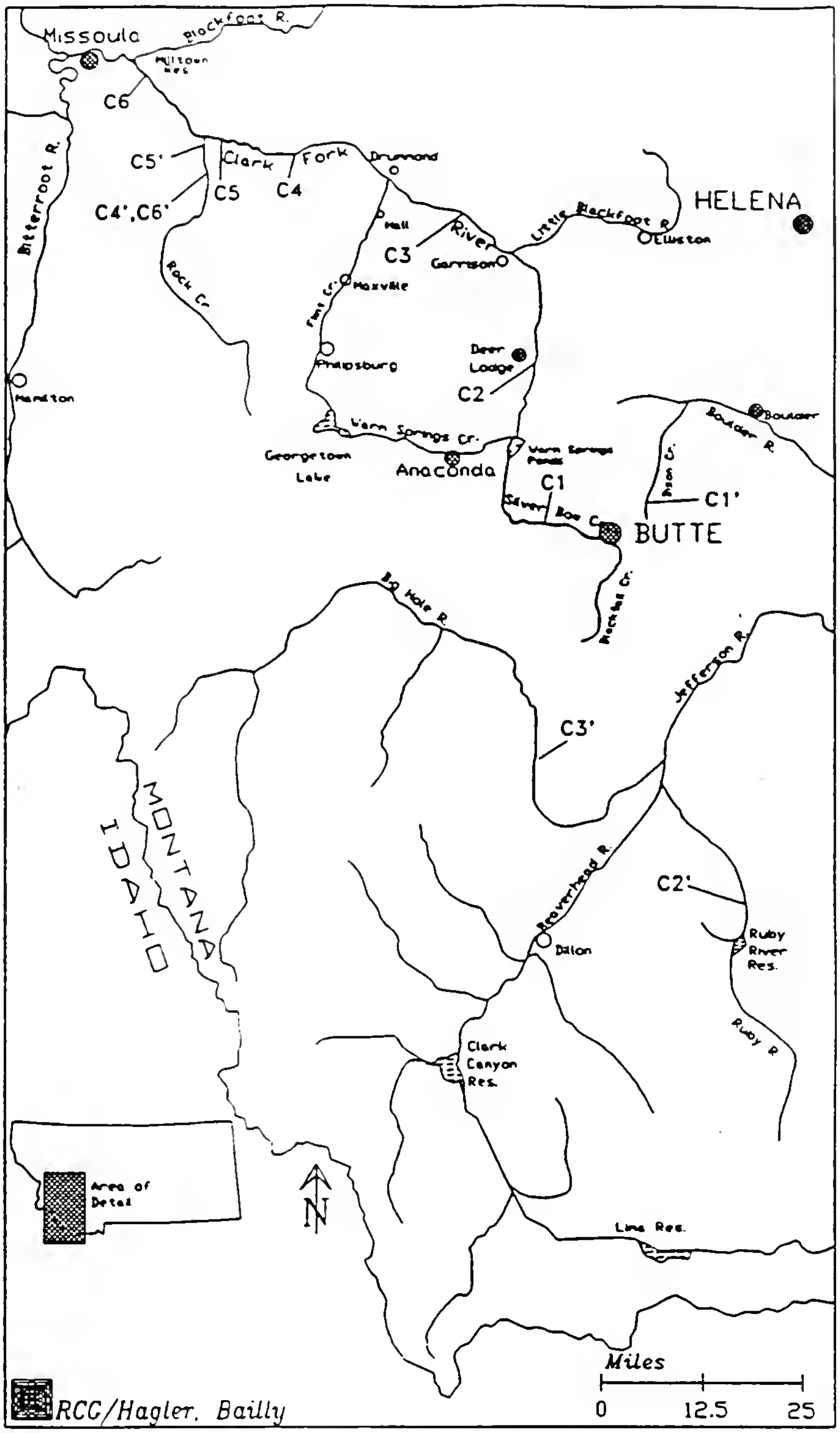

Figure 4-17. Fish Population Sites [impact (C1-C6) and controls (C1'-C6')] at which Surface Water Samples were Collected by NRDP.

Table 4-19
Comparison of Hazardous Substance Concentrations (U.S. EPA total recoverable) at Impact and Control Fish Population Sites (mean difference in concentration, ppb)*

Site Impact/Control	Cadmium		Copper		Lead		Zinc	
	Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value
Silver Bow Creek/Bison Creek	1.77	.05**	146.93	.05**	13.47	.0302**	516.17	.0462**
CFR at Deer Lodge/Ruby River	.08	.09	21.37	.0016**	1.10	.0262**	23.50	.0008**
CFR at Gold Creek/Big Hole River	.07	.12	19.55	.0006**	1.92	.0186**	21.33	.0028**
CFR at Bearmouth/Rock Creek	.03	.22	16.67	.0012**	1.95	.0322**	22.58	.0052**
CFR at Beavertail Hill/Rock Creek	.02	.50	15.48	.0016**	2.15	.0136**	23.55	.0050**
CFR at Turah/Rock Creek	.02	.50	12.92	.0042**	1.90	.0304**	21.92	.0004**

* Sample size equals 3 for Silver Bow Creek; 6 for all Clark Fork River sites.
** Indicated significantly greater concentration in Silver Bow Creek or the Clark Fork River at $\alpha=5\%$.

Table 4-20
Comparison of Hazardous Substance Concentrations (dissolved) at Impact and Control Fish Population Sites (mean difference in concentration, ppb)*

Site Impact/Control	Copper		Zinc	
	Mean Difference	p-value	Mean Difference	p-value
Silver Bow Creek/Bison Creek	54.87	.0474**	324.33	.0508**
CFR at Deer Lodge/Ruby River	7.42	.0008**	7.67	.0034**
CFR at Gold Creek/Big Hole River	3.78	.0006**	1.68	.0542
CFR at Bearmouth/Rock Creek	3.22	.0010**	1.03	.2142
CFR at Beavertail Hill/Rock Creek	2.88	.0014**	0.83	.1912
CFR at Turah/Rock Creek	0.88	.0166**	0.67	.2814

* Sample size equals 3 for Silver Bow Creek; 6 for all Clark Fork River sites.
** Indicated significantly greater concentration in Silver Bow Creek or the Clark Fork River at $\alpha = 5\%$.

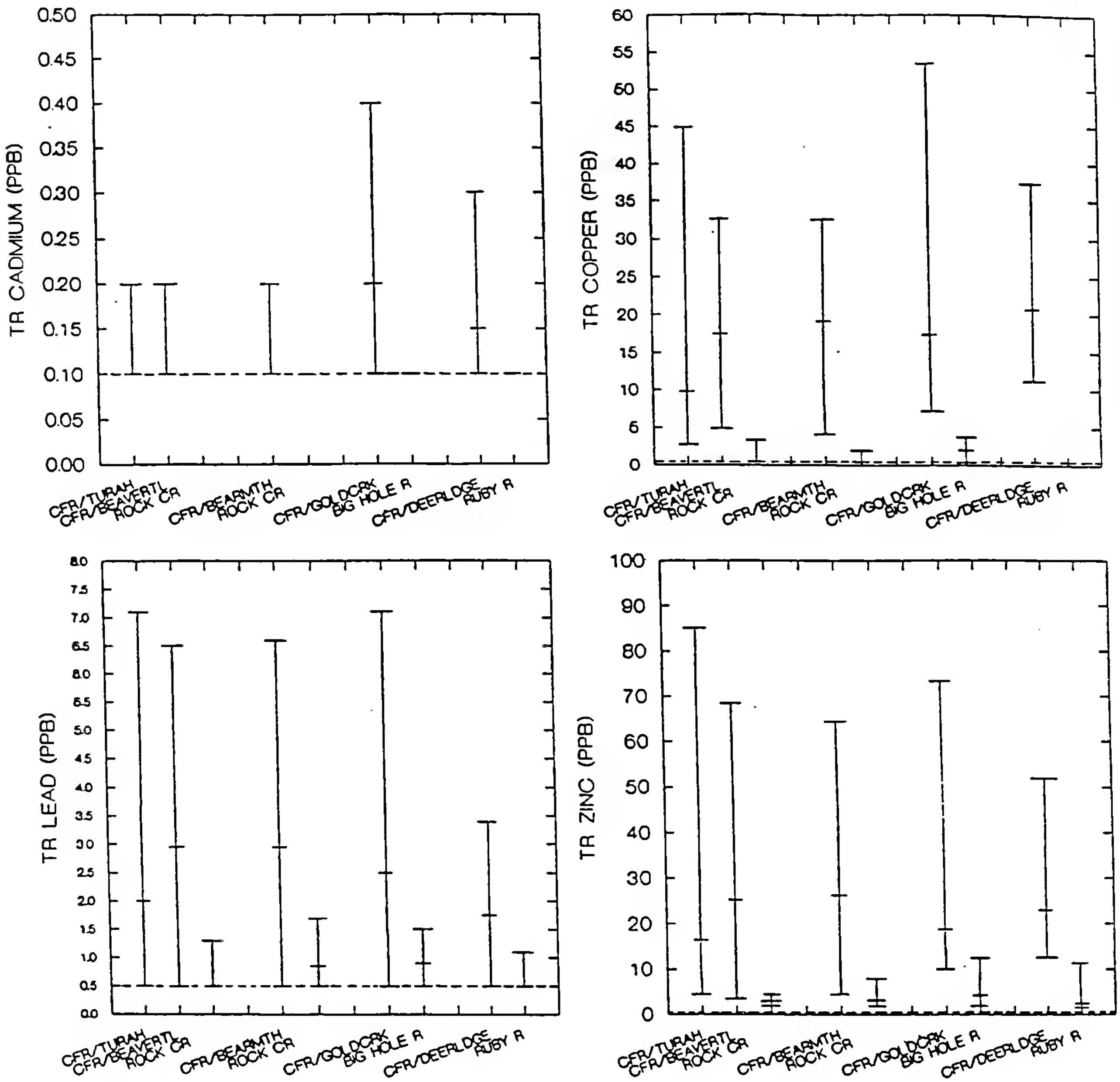

Figure --18. Concentrations of Hazardous Substances at Fish Population Impact and Control Sites (EPA total recoverable concentrations in ppb).

4.5 PATHWAYS OF HAZARDOUS SUBSTANCE MIGRATION TO THE CLARK FORK BASIN SURFACE WATER RESOURCES

The purpose of the pathway determination is to establish the route or media by which hazardous substances were or presently are transported from their sources to the surface water resource.

4.5.1 Pathways to Silver Bow Creek

The principal pathways of migration of hazardous substances from their sources to Silver Bow Creek are direct contact (as described in preceding sections), surface water/ sediments pathways, and groundwater pathways. These pathways are described below.

4.5.1.1 Surface Water/Sediments Pathway to Silver Bow Creek

The principal mechanisms by which surface water transports hazardous substances to other exposed surface waters include surface runoff and riverine transport.

Surface water runoff occurs during snowmelt and precipitation events. In the Butte area, storm-event and snowmelt runoff remobilize and transport hazardous substances from tailings deposits and other mining-related wastes (MultiTech, 1987c, 1987e; CH_2M Hill and Chen-Northern, 1990; CH_2M Hill, 1987). Runoff discharges to Silver Bow Creek through the city of Butte's storm drain system, or by drainage basins in the Butte area. Missoula Gulch, Buffalo Gulch, Anaconda Road-Butte Brewery drainage basin, Idaho Street, West-Side, Warren Avenue, and Grove Gulch contribute to the degradation of Silver Bow Creek through surface water discharge (CDM, 1991). These drainages all discharge to Silver Bow Creek (Figure 4-19). Runoff from large tailings deposits (e.g., the Colorado Tailings and Ramsay Flats) also enters Silver Bow Creek directly.

Elevated concentrations of cadmium, copper, lead, and zinc have been measured in surface runoff to Silver Bow Creek (Table 4-21). Butte storm drain runoff has been found to exceed chronic water quality criteria for both copper and zinc by one to two orders of magnitude. Runoff from streamside tailings has exceeded chronic criteria by three orders of magnitude.

Riverine transport serves as a pathway when hazardous substances are present in the water column (either dissolved or adsorbed to suspended sediments). Contaminant transport is most significant during high flows, when bank and channel sediments are remobilized (MultiTech, 1987c). Thus, hazardous substances are transported in both dissolved and sediment-bound forms.

Table 4-21
Concentrations of Hazardous Substances in Surface Runoff to Silver Bow Creek
(concentrations in $\mu g/l$ total recoverable)

Source	Cd	Cu	Pb	Zn
Missoula Gulch				
Snowmelt runoff March 10, 1989[1]	26	611	334	2,190
Storm event May 29, 1985[3]	146	4,020	875	21,300
SBC RI monitoring December 3, 1984[3]	14	916	75	4,340
SBC RI monitoring April 8, 1985[3]	2.9	424	444	2,200
Kaw Avenue storm drain				
Snowmelt runoff March 10, 1989[1]	5	593	267	1,160
Storm event May 29, 1985[3]	25	1,490	448	3,790
Harrison Avenue storm drain				
Snowmelt runoff March 10, 1989[1]	19	2,070	454	3,810
Weed concentrator complex				
Snowmelt runoff March 10, 1989[1]	90	17,400	454	16,800
Metro storm drain				
Snowmelt runoff March 10, 1989[1]	31	2,290	336	3,040
Baseflow sampling September 1988[2]	21	311	5.1	7,370
Storm event May 29, 1985[3]	89	10,600	1,500	9,970
SBC RI monitoring December 3, 1984[3]	36	728	150	1,320
SBC RI monitoring April 8, 1985[3]	3.4	953	13	5,980
SBC RI monitoring July 22, 1985[3]	12	327	9.8	6,260
Colorado tailings				
Snowmelt runoff March 10, 1989[1]	74	21,100*	87	27,200
Storm event runoff July 8, 1986[4]	928	233,000	161	282,000
Ramsay Flats				
Storm event runoff July 16, 1986[4]	1,250	202,000	3,100	264,000
Ambient water quality criteria (acute/chronic) (hardness = 200 mg/l)	8.6/2.0	34.1/21.4	197.3/7.7	210.6/190.7

* Indicates acid soluble concentration.

1 CH_2M Hill and Chen-Northern, 1990.
2 PTI, 1989.
3 MultiTech, 1987c, 1987e.
4 CH_2M Hill, 1987.

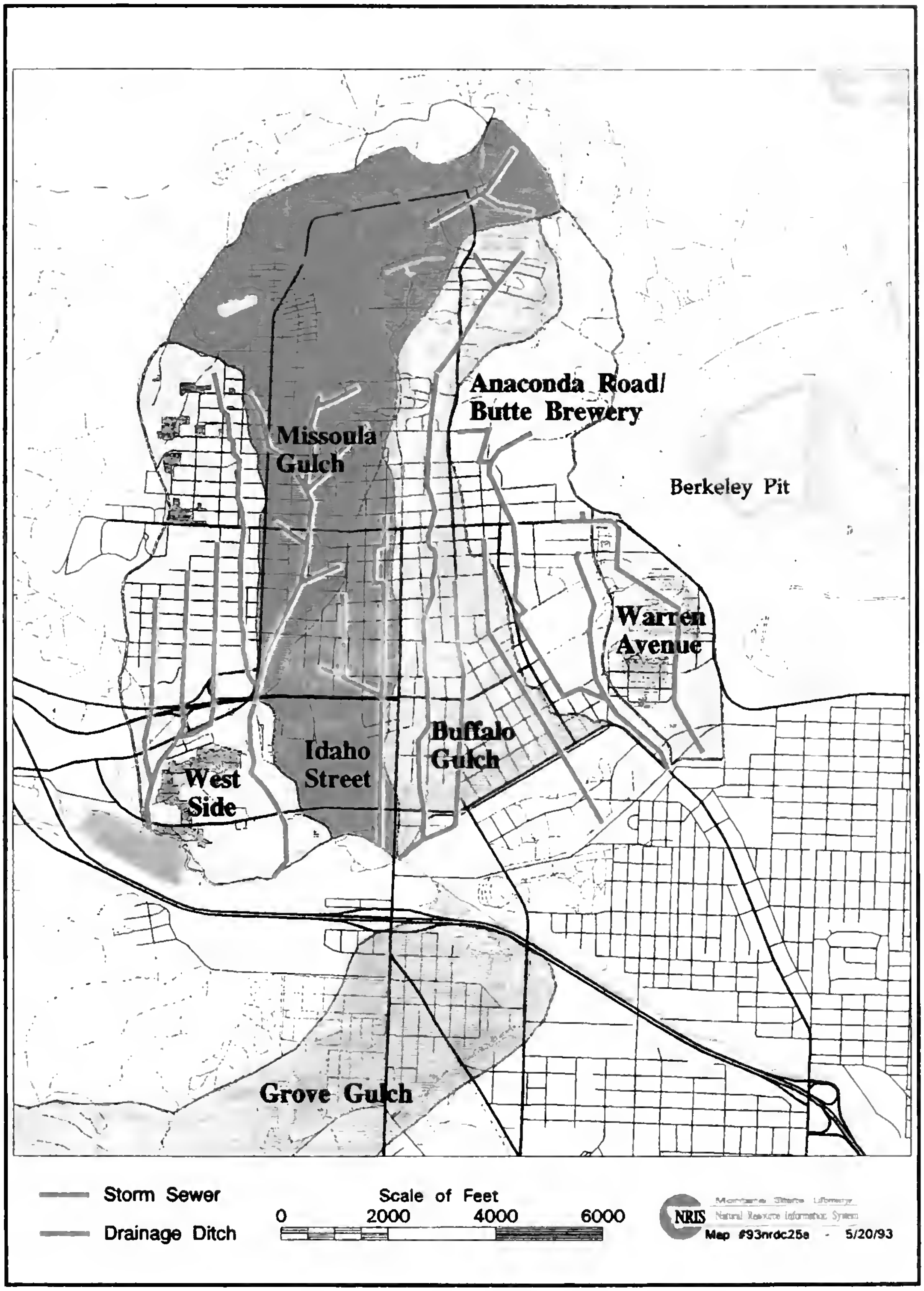

Figure 4-19. Butte Area Stormwater Basins.

4.5.1.2 Groundwater Pathway to Silver Bow Creek

Groundwater is an important exposure pathway to Silver Bow Creek. The SBC RI identified contaminated groundwater inflows to Silver Bow Creek in the areas of the Metro Storm Drain, and between Montana Street and the western end of the Colorado Tailings (MultiTech, 1987d). Groundwater quality in an area along the Metro Storm Drain from the Weed Concentrator to near Kaw Avenue is degraded by dissolved arsenic, cadmium, copper, iron, manganese, and zinc (MultiTech, 1987d). The area of degraded water appears to coincide with the location of the historic Silver Bow Creek channel (MultiTech 1987d). Alluvial groundwater has been identified as the source of metals contamination (copper and zinc) in Silver Bow Creek, specifically in the reach between Montana Street and the Colorado Tailings (MultiTech, 1987b, as cited in CDM, 1990). Alluvial groundwater at Lower Area I flows through the Butte Reduction Works and the Colorado Tailings before discharging to Silver Bow Creek (U.S. EPA, 1992). The inflow of metals and arsenic-laden groundwater from the Butte Reduction Works and the Colorado Tailings contributes substantially to exceedences of both chronic and acute aquatic water quality criteria for copper, zinc, and cadmium in Silver Bow Creek during baseflow and low flow conditions (CH_2M Hill and Chen Northern, 1990; MultiTech, 1987, as cited in U.S. EPA, 1992).

Tables 4-22 and 4-23 present metals concentrations in groundwater in Lower Area I and the Colorado Tailings, respectively. These concentrations substantially exceed ambient water quality criteria.

Table 4-24 presents estimated metals loadings from groundwater recharge. The importance of the groundwater pathway is demonstrated by its contribution to the total metal loading into the creek. For example, the copper loading from Montana Street area groundwater (7.5 pounds per day) represents a 379% increase in the copper loading to Silver Bow Creek (a contribution greater than 100% indicates that loading from groundwater is greater than the surface water loading in the stream reach upstream of the groundwater recharge area).

4.5.2 Pathways to the Clark Fork River

The principal pathways of migration of hazardous substances from sources to the Clark Fork River are surface water/sediments and groundwater. These pathways are described below.

Table 4-22
Concentrations of Hazardous Substances in Lower Area I Wells, Compared to AWQC (concentrations in μg/l)[1]

Source	Statistic	As	Cd	Cu	Pb	Zn
17 wells between 0 and 10 feet in depth	Mean Minimum Maximum	282 1.7 2,200	146 0.39 937	23,353 <1.1 98,000	266 <0.5 3,520	50,637 29.6 220,000
13 wells between 10 and 40 feet in depth	Mean Minimum Maximum	513 0.6 1,200	77 <5 540	1,370 <1.1 17,000	20.3 <0.5 180	25,188 <20 160,000
Ambient water quality criteria (hardness = 200 mg/l)	Acute Criterion Chronic Criterion	360 190	8.6 2.0	34.1 21.4	197.3 7.7	210.6 190.7

1 U.S. EPA, 1992.

Table 4-23
Maximum Concentrations of Hazardous Substances in Groundwater Beneath the Colorado Tailings (dissolved concentrations in ppb)

Well Number (depth)		As	Cd	Cu	Pb	Zn
BMW-2T (4 feet)		0	510	98,000	45	170,000
BMW-2A (16 feet)		5,000	340	20,000	180	110,000
BMW-2B (50 feet)		4,100	790	68,000	15	240,000
Ambient water quality criteria (hardness = 200 mg/l)	Acute Criterion	360	8.6	34.1	197.3	210.6
	Chronic Criterion	190	2.0	21.4	7.7	190.7

Source: CH_2M Hill and Chen-Northern, 1990.

Table 4-24
Estimated Loadings of Hazardous Substances to Silver Bow Creek from Groundwater (pounds per day)*

Stream Reach	Cd Loading	% Cd Contrib.	Cu Loading	% Cu Contrib.	Pb Loading	% Pb Contrib.	Zn Loading	% Zn Contrib.
Metro storm drain (MSD)[1] area groundwater	.07	99.4	1.8	25.4	.01	53.0	22.9	77.1
Montana Street[2] area groundwater	.11	245	7.5	379	.03	25.4	19.6	259
Lower Area I[3] groundwater (low flow conditions)	NC	NC	14.5	NC	NC	NC	62.7	NC
Colorado Tailings[2] area groundwater	.10	147	7.9	68.6	.01	9.0	39.9	125
Colorado Tailings[4] area groundwater	NC	NC	NC	66	NC	NC	NC	66
Colorado Tailings area (July 1987-June 1988)[5]	NC	NC	15.3	NC	NC	NC	64.7	NC
Colorado Tailings area[6]	NC	NC	NC	>70	NC	NC	NC	>70
Colorado Tailings area[7] (August 1989)	.27	NC	23.5	NC	NC	NC	108	NC

* NC = not calculated.

1 MultiTech, 1987c (loadings during low flow expressed as a percentage of measurements at the confluence of the MSD with Silver Bow Creek).
2 MultiTech, 1987c (loadings during low flow expressed as a percentage of measurements at the stream station above the area of groundwater inflow).
3 U.S. EPA, 1992.
4 Rouse, 1977, as cited in U.S. EPA, 1992.
5 Ingman and Kerr, 1990a.
6 Duaime *et al.*, 1990, as cited in U.S. EPA, 1992.
7 Hydrometrics, 1990.

4.5.2.1 Surface Water/Sediments Pathway to the Clark Fork River

The surface water discharge from the Warm Springs Ponds is a pathway to the Clark Fork River for hazardous substances in Silver Bow Creek and Warm Springs Ponds surface waters (see Table 4-25 for metals concentrations in the Silver Bow Creek inflow to the Warm Springs Ponds). Although Silver Bow Creek is the primary surface water inflow to the Warm Springs Ponds, inflow to the Ponds also includes the North and South Opportunity Ponds discharges, which average 0.97 cfs and 1.3 cfs respectively (MDHES and CH_2M Hill, 1989). Hazardous substance concentrations in the Warm Springs Pond 2 discharge (Table 4-26) regularly exceed ambient AWQC.

Warm Springs Creek, Mill Creek, and Willow Creek, although generally considered to be medium to high quality waters, occasionally transport hazardous substances from sources in the Anaconda area to the Clark Fork River. Historical operating practices at the Old Works included sluicing unknown quantities of concentrator tailings into Warm Springs Creek (Tetra Tech, 1987). Elevated metals concentrations have been documented in Warm Springs Creek during high flows (Ingman and Kerr, 1990b; ESE Inc., 1991). The results of hydraulic modeling (PTI, 1991) indicate that erosion and transport of various waste deposits in the Old Works near to or within the floodplain of Warm Springs Creek is likely during very high flows. Mill Creek flows less than 1 mile from Smelter Hill, and inflow of surface water from contaminated soils is the likely cause of declining water quality (Tetra Tech, 1987). Tailings carried by Silver Bow Creek into the lower Willow Creek watershed may be a factor in its contamination (Tetra Tech, 1987). Table 4-27 provides examples of metals concentrations in these surface water pathways.

Surface water runoff from streamside tailings associated with precipitation events also acts as a surface water pathway. High-intensity runoff events from the Mill-Willow Bypass were responsible for several fishkills in the upper Clark Fork River in the 1980s (see Chapter 6.0). MDHES and CH_2M Hill (1989) identified tailings and metal salts in the Mill-Willow Bypass as sources of hazardous substances to the Bypass and the Clark Fork River during thunderstorms.

Riverine transport is the primary mechanism of surface water transport of hazardous substances from upstream sources to downstream reaches in the Clark Fork River. ENSR (1992) estimate that average annual sediment deposition in the Milltown Reservoir was approximately 10,000 tons per year over a 51-year simulation period. Lambing (1991) estimated that Milltown Reservoir sediment deposition was approximately 16,300 tons per year during water years 1985-1990.

Table 4-25
Range of Hazardous Substance Concentrations in Silver Bow Creek Entering Warm Springs Ponds
(Montana total recoverable concentrations In ppb)

Year		Cadmium	Copper	Lead	Zinc
1983		NA	120 - 1,349	NA	280 - 1,839
1984		NA	110 - 3,000	NA	370 - 820
1985		NA	80 - 430	NA	255 - 900
1986		NA	70 - 690	NA	151 - 1,120
1987		NA	70 - 520	NA	32 - 994
1988		2 - 3	17 - 2,200	9 - 48	19 - 3,740
1989		1 - 26.2	100 - 2,540	6 - 122	272 - 8,080
1990		0.6 - 3.1	67 - 437	3 - 52	202 - 1,240
1991		1.1 - 3.7	111 - 288	16 - 44	271 - 746
Ambient water quality criteria (hardness = 200 mg/l)	Acute Criterion	8.6	34.1	197.3	210.6
	Chronic Criterion	2.0	21.4	7.7	190.7

Source: STORET; MDHES, 1990, 1991.

Table 4-26
Concentrations of Hazardous Substances in the Warm Springs Pond 2 Discharge
(Montana total recoverable concentrations in ppb)

Year	Cd Range	Cd Median	Cu Range	Cu Median	Pb Range	Pb Median	Zn Range	Zn Median
1983	NA	NA	<10 - 190	35+	NA	NA	20 - 260	90
1984	NA	NA	<10 - 120*	20	NA	NA	20 - 470	120
1985	NA	NA	<10 - 100**	30+	NA	NA	15 - 495	132
1986	NA	NA	<10 - 160*	30+	NA	NA	19 - 693	54
1987	NA	NA	<10 - 40*	20	NA	NA	7 - 191	43
1988	<.2 - .3	<.2	3 - 30**	10	<1 - 4	<1	6 - 156	51
1989	<.2 - .2	<.2	7 - 210*	20	<1 - 55**	2	10 - 576*	58
1990	<.2 - .4	<.2	6 - 57*	16	<1 - 10**	1	4 - 115	40
1991	<.2 - .9	.4	16 - 49*	24+	1 - 52**	4	43 - 118	61
Average	<.2 - .4	.2	6 - 106	23+	<1 - 30	2	16 - 342	72

Ambient water quality criteria (hardness = 200 mg/l)	Cd	Cu	Pb	Zn
Acute Criterion	8.6	34.1	197.3	210.6
Chronic Criterion	2.0	21.4	7.7	190.7

* Range of concentrations includes at least one acute criteria exceedence.
** Range of concentrations includes at least one chronic criteria exceedence.
\+ Median concentration exceeds chronic criterion (hardness = 200 mg/l).

Source: STORET; MDHES, 1990, 1991.

Table 4-27
Concentrations of Hazardous Substances in Warm Springs Creek, Mill Creek, and Willow Creek Surface Water Pathways to the Clark Fork River
(total concentrations in $\mu g/l$)

Location	Number of Samples	Arsenic	Copper	Lead	Zinc
Warm Springs Creek					
Range		3 - 10	1.3 - 24	<3 - 6	<3 - 22
Geometric Mean	24	<5.2	<5.4	<3.3	<6.9
Mill Creek					
Range		10 - 32	<1.3 - 12	<3 - 8	<3 - 20
Geometric Mean	12	21	<4.8	<3.6	<8.8
Willow Creek					
Range		30 - 62	<1.3 - 28	3 - 17	10 - 35
Geometric Mean	4	42	<7.6	5.3	24

Source: Tetra Tech, 1987.

4.5.2.2 Groundwater Pathway to the Clark Fork River

Groundwater samples collected during the Warm Springs Ponds RI indicated degradated groundwater in the shallow aquifer underneath and below Pond 1 (ESA, 1991). This groundwater flows northward and ultimately discharges to the Mill-Willow Bypass, Silver Bow Creek below the Bypass, or the Clark Fork River (ESA, 1991). Under average conditions, the flow in the Clark Fork River is approximately 137 cfs, while the groundwater recharge to the river from the area below Pond 1 is approximately 1.0 cfs (MDHES and CH_2M Hill, 1989). Metals concentrations in samples collected from shallow (generally less than 15 feet) and deep (generally 15 to 40 feet deep) wells in the Pond 1 area and below are presented in Table 4-28.

The combined flows of Mill and Willow Creeks are generally degraded in the Mill-Willow Bypass by recharge of contaminated groundwaters from Opportunity Ponds and Warm Springs Ponds. Approximately 2.5 cfs of groundwater from the Warm Springs Ponds recharges to the Mill-Willow Bypass (MDHES and CH_2M Hill, 1989). Groundwater quality beneath Ponds 2 and 3 was not investigated during the RI. Wells located between the Mill-Willow Bypass and the Warm Springs Ponds contained elevated

Table 4-28
Concentrations of Hazardous Substances in Groundwater Pathway to the Clark Fork River Below Warm Springs Ponds ($\mu g/l$)

Description	As	Cd	Cu	Pb	Zn
Shallow Wells (generally <15 feet deep)					
Maximum	197.0	12.7	15.9	<2.0	253
Minimum	<2.0	<5.0	<6.0	<1.0	16.3
Average	28.0	3.6	5.8	2.0	89.0
Deep Wells (generally 25 to 40 feet deep)					
Maximum	<3.0	8.4	<8.0	<2.0	43
Minimum	<2.0	<5.0	<6.0	<1.0	6.2
Average	1.0	4.3	3.5	0.8	19.8

Source: MDHES and CH_2M Hill, 1989.

concentrations of hazardous substances compared to upgradient monitoring wells (Table 4-29). Another 0.7 cfs of groundwater from the Opportunity Ponds area was calculated to recharge to the Bypass. The combined inputs of these groundwater inflows increase hazardous substance loadings along the Bypass by approximately 30% during baseflow conditions of 13 cfs (MDHES and CH_2M Hill, 1989).

Groundwater from beneath the Opportunity Ponds also recharges to Warm Springs Creek. Less than 2 cfs of groundwater discharges directly to the creek; 3-5 cfs discharges via the North Drain (Tetra Tech, 1987). This groundwater recharge probably does not have a significant impact on hazardous substance concentrations in Warm Springs Creek (Tetra Tech, 1987) but is nonetheless another pathway by which metals migrate to the Clark Fork River surface water resource.

Table 4-29
Concentrations of Hazardous Substances in Groundwater Along the Mill-Willow Bypass Compared to Upgradient Groundwater ($\mu g/l$)

Description	As	Cd	Cu	Pb	Zn
Shallow Wells (generally <15 feet deep)					
Maximum	41.0	11.7	15.0	18.0	1250
Minimum	<2.0	<5.0	<6.0	<1.0	12.7
Average	9.2	3.7	4.6	2.5	265
Deep Wells (generally 25 to 40 feet deep)					
Maximum	<2.0	5.2	7.1	2.0	38.0
Minimum	<2.0	<5.0	<6.0	<1.0	6.2
Average	1.1	2.9	4.0	1.1	22.2
Upgradient wells					
Maximum	6.8	7.0	9.7	1.2	21.2
Minimum	2.6	<5.0	6.1	<1.0	4.7
Average	4.3	3.4	5.8	0.84	10.3

Source: MDHES and CH_2M Hill, 1989.

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5.0 BENTHIC MACROINVERTEBRATES

5.1 INTRODUCTION

Benthic macroinvertebrates are invertebrates that live principally on stream or lake bottoms. They span a wide range of life histories and ecologies, from plant-eating "scrapers" to predators that prey on other invertebrates. Many are the larval, or juvenile stages, of insects and emerge from the stream or lake as flying or terrestrial adults. Benthic macroinvertebrates are essential in nutrient and energy cycling in aquatic ecosystems and are integral components of the aquatic food chain (ASTM E 1383-1390, as cited in U.S. FWS and University of Wyoming, 1992). They are the primary food source for many fish species (U.S. EPA, 1989a). Since they are in intimate contact with sediments, exhibit a wide range of sensitivity to hazardous substances, occupy limited home ranges, and are relatively easy to monitor (U.S. EPA, 1989a; U.S. EPA, 1989b), benthic macroinvertebrates have been used extensively to monitor the effects of sediment contamination on aquatic ecosystems (Burton, 1992).

In this chapter, two distinct topics relating to benthic macroinvertebrates are presented:

1. In Silver Bow Creek and in the Clark Fork River, benthic macroinvertebrates have been exposed to and have bioaccumulated hazardous substances (Section 5.2). Because of this accumulation, benthic macroinvertebrates are a critical pathway by which fish are exposed to, and injured by, hazardous substances (see Chapter 6.0).

2. In Silver Bow Creek, benthic macroinvertebrates have been injured as a result of exposure to hazardous substances in contaminated streambed sediments (Section 5.3). A similar pattern of impacts may be present in the Clark Fork River.

5.2 BENTHIC MACROINVERTEBRATES AS A PATHWAY TO FISH: ACCUMULATION OF HAZARDOUS SUBSTANCES

Benthic macroinvertebrates are known to accumulate hazardous substances from the surface water column and sediments (Lee, 1992). Since benthic macroinvertebrates are the primary food source for many fish species, fish are exposed to hazardous substances accumulated in macroinvertebrates. Chapter 6.0 of this report details injuries to fish caused by consumption of contaminated benthic macroinvertebrates from the Clark Fork River.

5.2.1 Silver Bow Creek Benthic Macroinvertebrate Hazardous Substances Tissue Concentrations

Concentrations of hazardous substances in Silver Bow Creek benthic macroinvertebrate tissues were measured in a study by the U.S. FWS and the University of Wyoming conducted as part of a U.S. EPA Superfund Remedial Investigation (U.S. FWS and University of Wyoming, 1992). Hazardous substances were measured in tissues of macroinvertebrates collected from Silver Bow Creek near Warm Springs Ponds and from a control stream (Rock Creek) (Table 5-1). In addition, hazardous substance concentrations were measured in the amphipod *Hyalella azteca* after being exposed in the laboratory for 28 days to sediments that were collected from the same stations in Silver Bow Creek and Rock Creek (control) (Table 5-1). During the 28-day laboratory exposure, a significantly higher number of amphipods exposed to Silver Bow Creek sediments died than amphipods exposed to control sediments. Since these dead organisms were not analyzed for hazardous substances, the reported tissue concentrations may underestimate hazardous substance concentrations which accumulated in amphipods exposed to Silver Bow Creek sediments.

Differences in mean concentrations in field-collected invertebrates from Silver Bow Creek and the control stream (Rock Creek) were compared using two-sample randomization tests (Manly, 1991). Concentrations of hazardous substances in invertebrates collected from Silver Bow Creek were found to be significantly higher than those from the control stream (Table 5-1). Bioaccumulation of hazardous substances from Silver Bow Creek sediments was also confirmed in the controlled laboratory uptake experiments, although sample sizes were not large enough for statistical testing.

Table 5-1
Mean Metals Concentrations in Benthic Macroinvertebrates, Silver Bow Creek and Control

		Hazardous Substance Concentration (ppm dry weight)				
Organism	**Location**	**Arsenic**	**Cadmium**	**Copper**	**Lead**	**Zinc**
Field-collected invertebrates	Silver Bow Creek	34.1*	8.38*	1382*	67.1*	1665*
	Control (Rock Creek)	2.7	0.13	26	0.54	212
Lab-exposed amphipods (no statistics performed)	Sediment from Silver Bow Creek	7.44	2.04	249	7.27	259
	Sediment from control (Rock Creek)	0.39	1.66	80	0.87	57

* Significant at $p < 0.03$ (vs. control).

Source: U.S. FWS and University of Wyoming, 1992.

5.2.2 Clark Fork River Benthic Macroinvertebrate Hazardous Substances Tissue Concentrations

Chapter 6.0 describes studies that demonstrate injury to fish caused by consumption of hazardous substance-contaminated invertebrates collected from the Clark Fork River. Fish that were fed diets consisting of contaminated invertebrates had reduced survival, decreased growth, and physical deformations relative to fish fed control diets. These studies demonstrate the importance of the food chain pathway in causing injury to fish in the Clark Fork River.

Several investigations have been conducted on bioaccumulation of hazardous substances in benthic macroinvertebrates in the Clark Fork River (Cain *et al.*, 1992; U.S. FWS and University of Wyoming, 1992). These investigations measured hazardous substances concentrations in tissues of macroinvertebrates collected from different stations along the Clark Fork River and from tributaries to the Clark Fork River that served as control areas. Cain *et al.* (1992) collected invertebrates from the Little Blackfoot River, Rock Creek, and Blackfoot River for use as controls. U.S. FWS and the University of Wyoming (1992) used samples from Rock Creek as controls. The U.S. FWS study also measured hazardous substances concentrations in the amphipod *Hyalella azteca* exposed for 28 days in the laboratory to sediments that were collected from the same Clark Fork River and control stations from which macroinvertebrates were collected. Table 5-2 and Figures 5-1 through 5-9 present the mean hazardous substances concentrations measured in field-collected benthic macroinvertebrates (Cain *et al.*, 1992, [raw data in USGS, 1986]; U.S. FWS and University of Wyoming, 1992).

Differences in observed mean hazardous substances concentrations between Clark Fork River invertebrates and control stream invertebrates were compared using two-sample randomization tests (Manly, 1991). As shown in Table 5-2, mean hazardous substance concentrations are significantly higher (using a one-tailed p-value) in Clark Fork River invertebrates than in invertebrates collected from control streams (except for arsenic in invertebrates collected from Turah).

Cain *et al.* (1992) conducted a correlation analysis between metals concentrations in field-collected invertebrates and metals concentrations in sediments at the collection location. Table 5-3 presents the results. For the taxa *Hydropsyche* spp. and *Isogenoides* spp., which were found throughout the length of the Clark Fork River between Warm Springs Ponds and Milltown, concentrations of copper and cadmium in tissues were significantly correlated with sediment concentrations. Concentrations of lead and zinc were also significantly correlated in *Hydropsyche* spp., but not in *Isogenoides* spp. The strong correlations indicate that hazardous substance uptake and bioaccumulation in Clark Fork River invertebrates is associated with elevated sediment concentrations.

Table 5-2
Mean Metals Concentrations in
Benthic Macroinvertebrates Collected from the Clark Fork River

			Mean Hazardous Substance Concentrations (ppm dry weight)				
Organism	**Location**		**As**	**Cd**	**Cu**	**Pb**	**Zn**
Field-collected *Hydropsyche* spp.[1]	Clark Fork River	0-60 mi.[3] (n=4)	NA	3.4**	140*	11.2*	254*
		60-120 mi.[3] (n=4)	NA	2.1***	65*	6.6*	226*
	Control areas		NA	0.2	19	0.8	111
Field-collected invertebrates[2] (n=5 at each location)	Clark Fork River	At Warm Springs (0 mi.)	14.6***	1.2**	122***	10.7***	304**
		At Deer Lodge (21.5 mi.)	13.1***	1.4***	181***	9.9**	293**
		At Gold Cr. Bridge (47.7 mi.)	26.8**	2.2**	266***	32.2**	453**
		At Turah (112.6 mi.)	3.4	1.8***	48***	3.8***	359***
	Control areas		2.7	0.13	26	0.54	212

* p-value < 0.05 (vs. controls).
** p-value < 0.01.
*** p-value < 0.005.
NA = not available.

1 USGS, 1986.
2 U.S. FWS and University of Wyoming, 1992.
3 Clark Fork River 0-60 miles is from Warm Springs to above Flint Cr.; 60-120 miles is from above Flint Cr. to Milltown.

Table 5-3
Correlation of Whole-body Invertebrate Concentrations and Bed Sediment Concentrations
(Data Collected in 1986)

	Correlation Coefficient (r)			
Taxon	**Copper**	**Cadmium**	**Lead**	**Zinc**
Hydropsyche spp. (n=13)	0.86 ***	0.71 **	0.74 **	0.74 **
Isogenoides spp. (n=12)	0.74 **	0.66 *	0.36 (n=11)	0.25

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Source: Cain *et al.*, 1992.

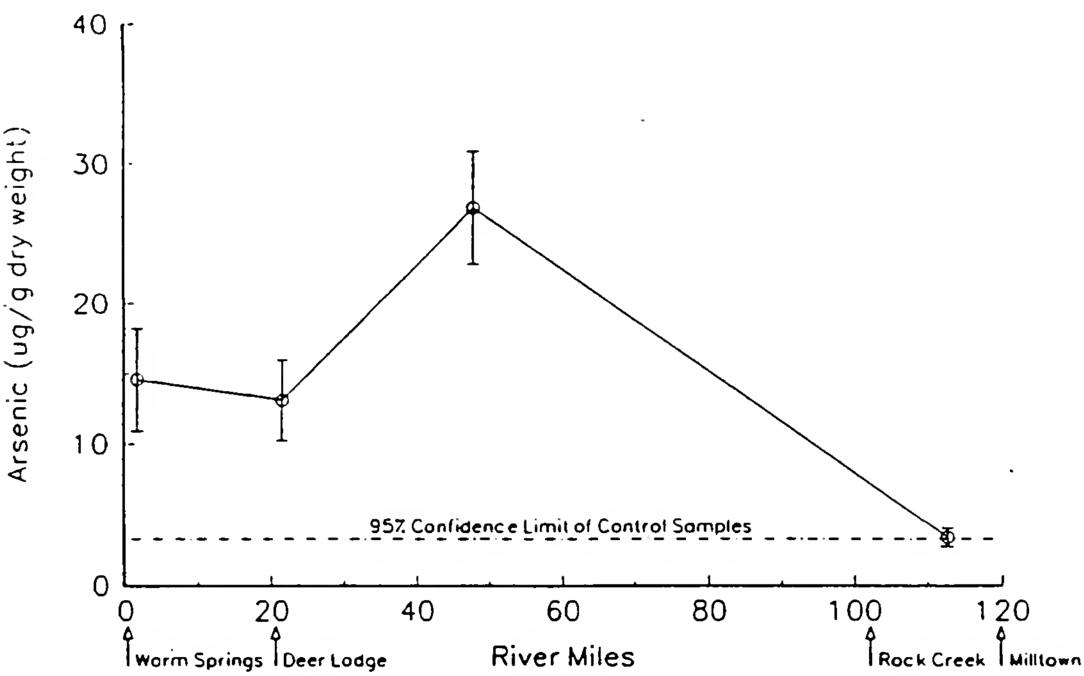

Figure 5-1. Arsenic in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

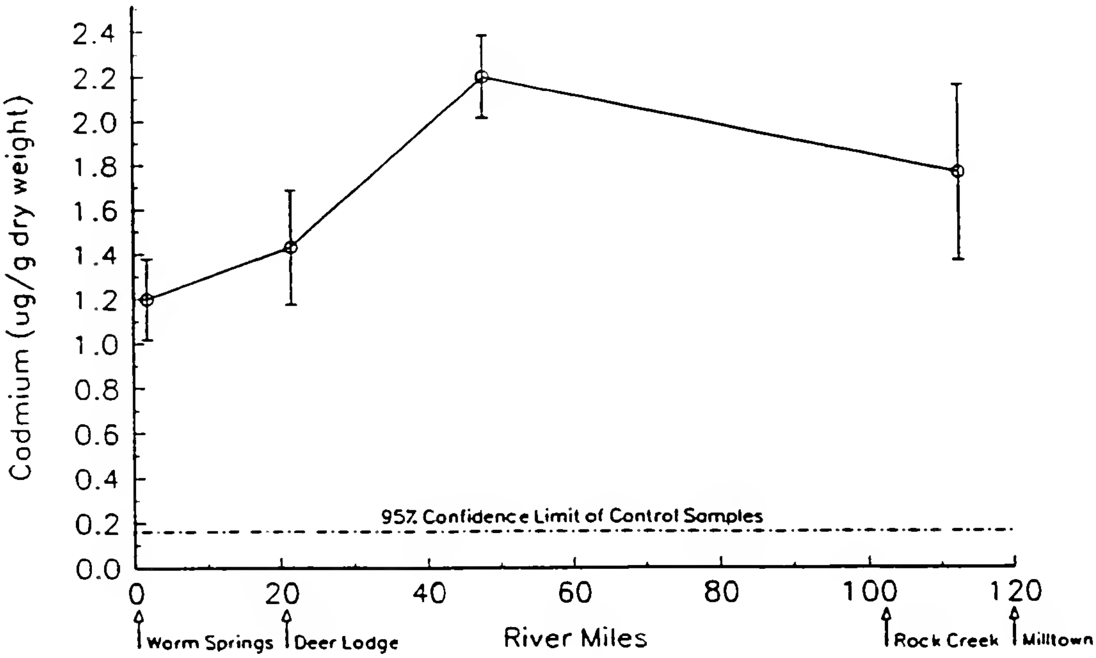

Figure 5-2. Cadmium in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

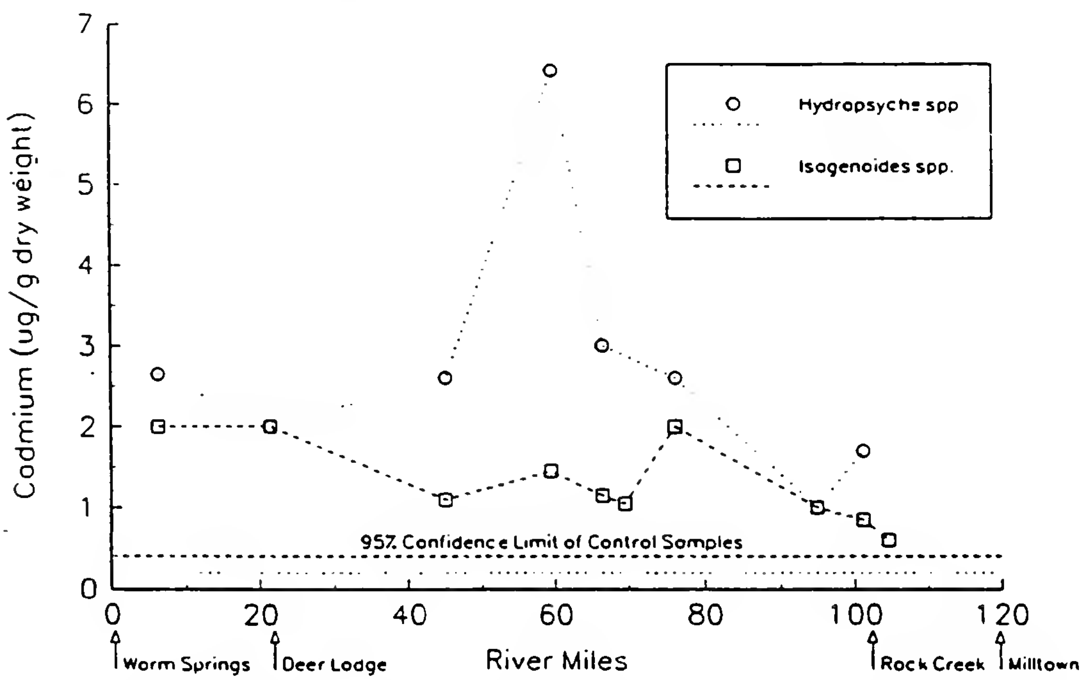

Figure 5-3. Cadmium in Field-Collected Invertebrates, Clark Fork River. Source: USGS, 1986.

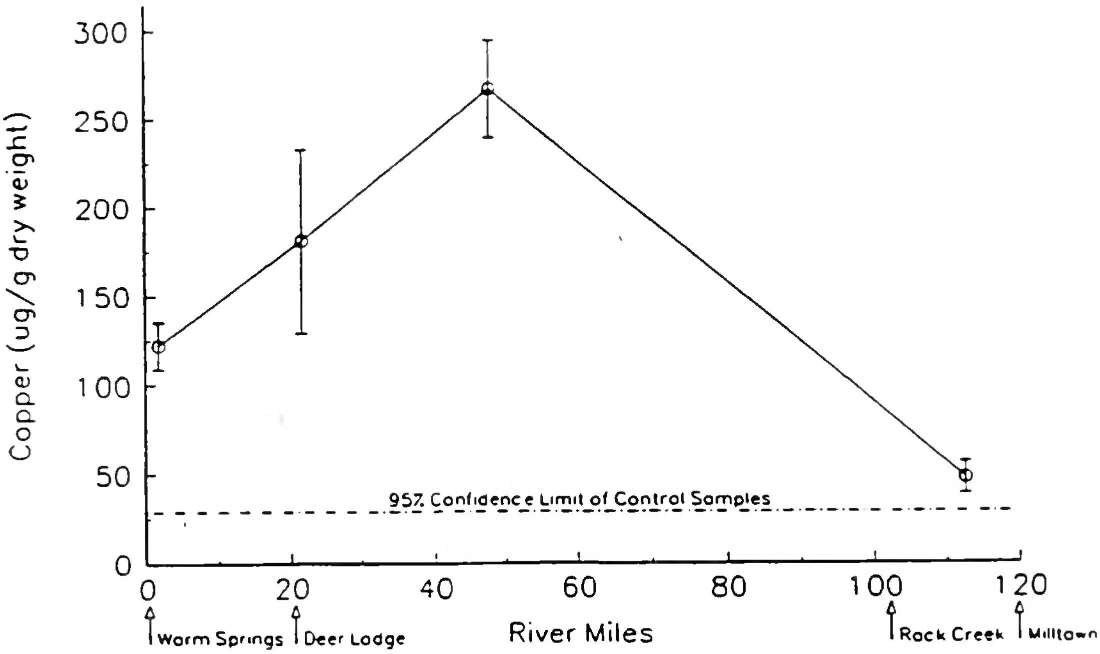

Figure 5-4. Copper in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

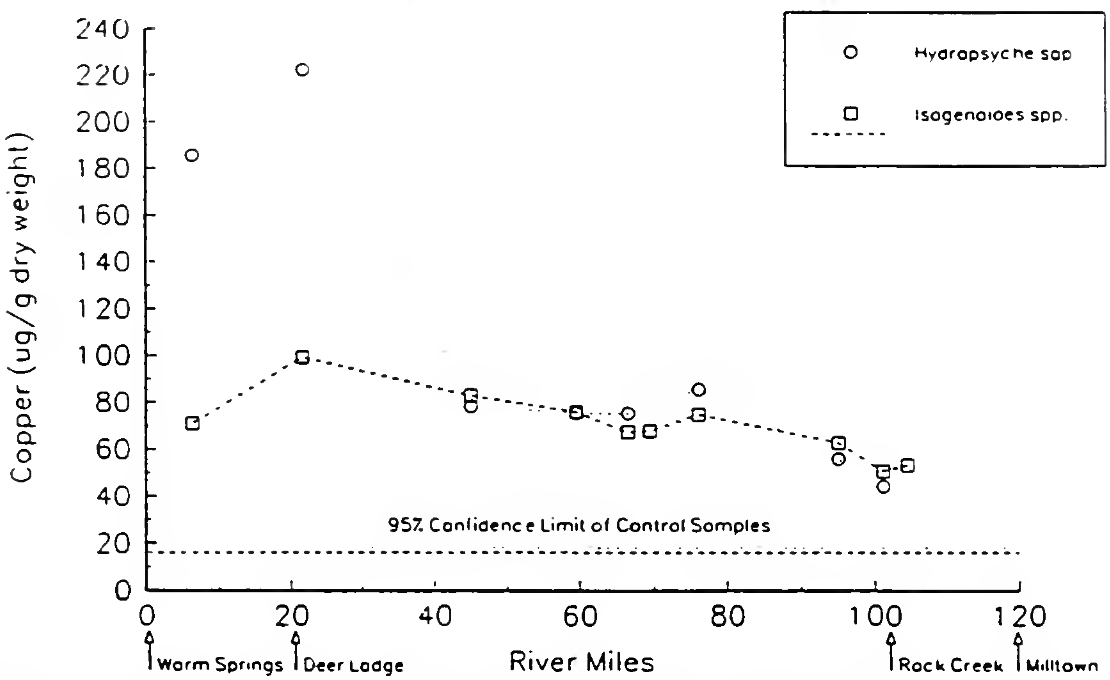

Figure 5-5. Copper in Field-Collected Invertebrates, Clark Fork River. Source: USGS, 1986.

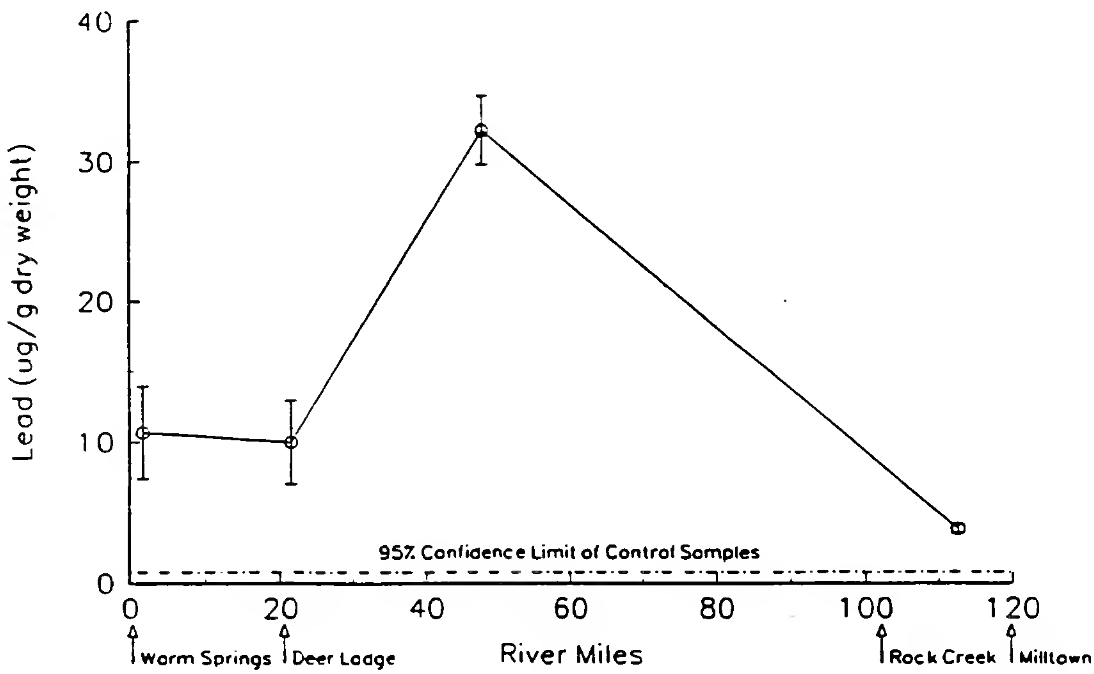

Figure 5-6. Lead in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

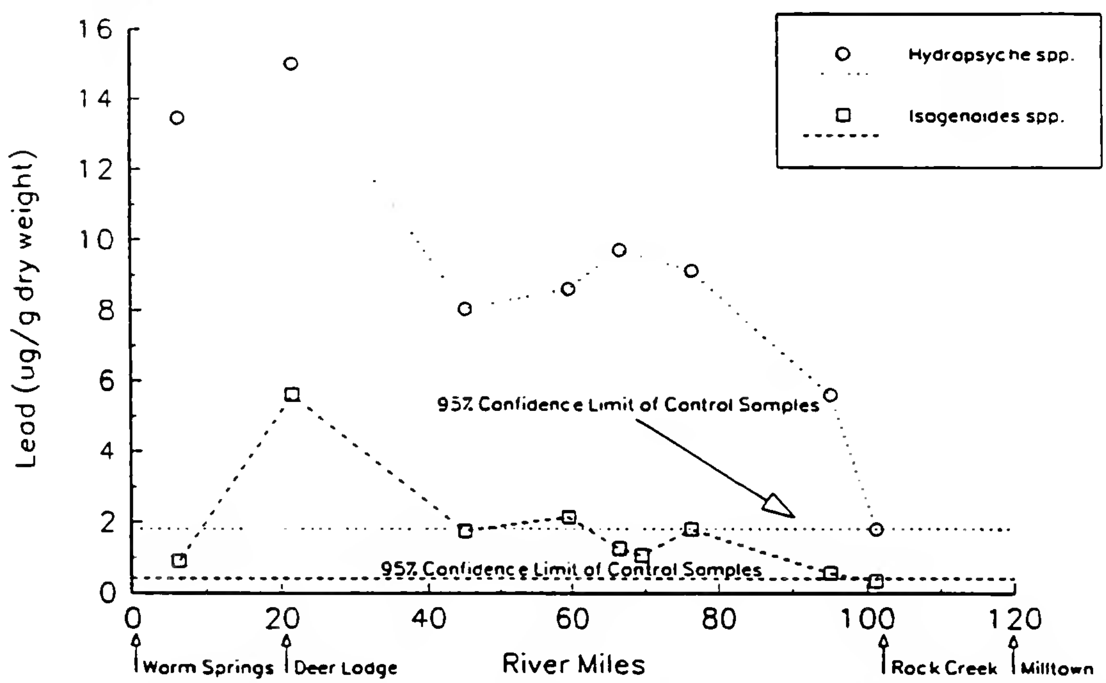

Figure 5-7. Lead in Field-Collected Invertebrates, Clark Fork River. Source: USGS, 1986.

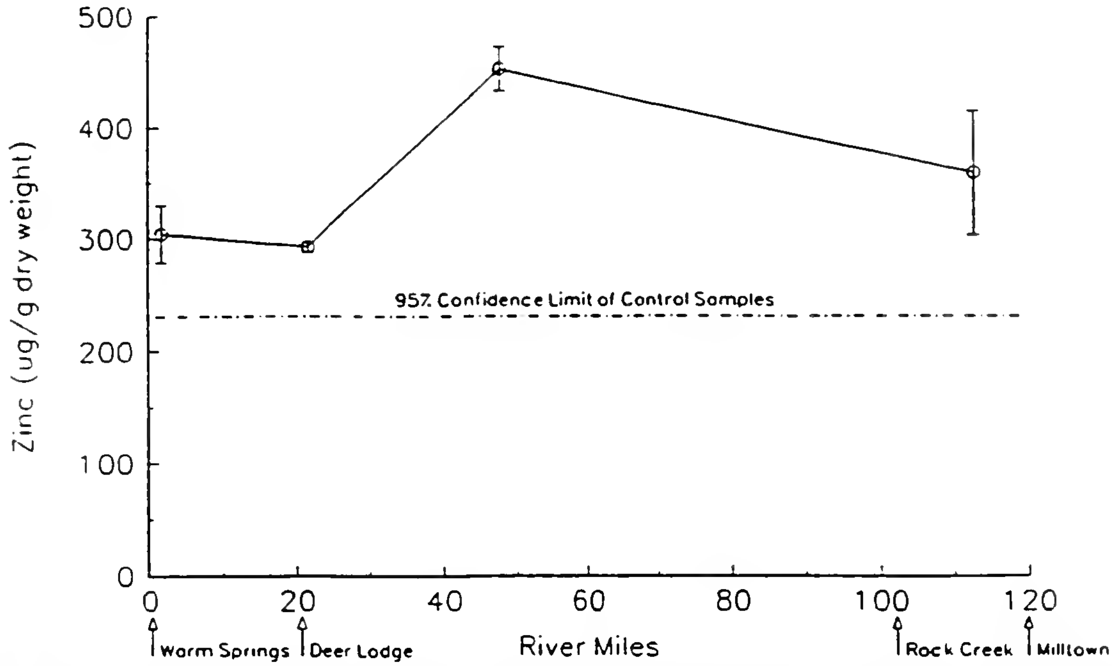

Figure 5-8. Zinc in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

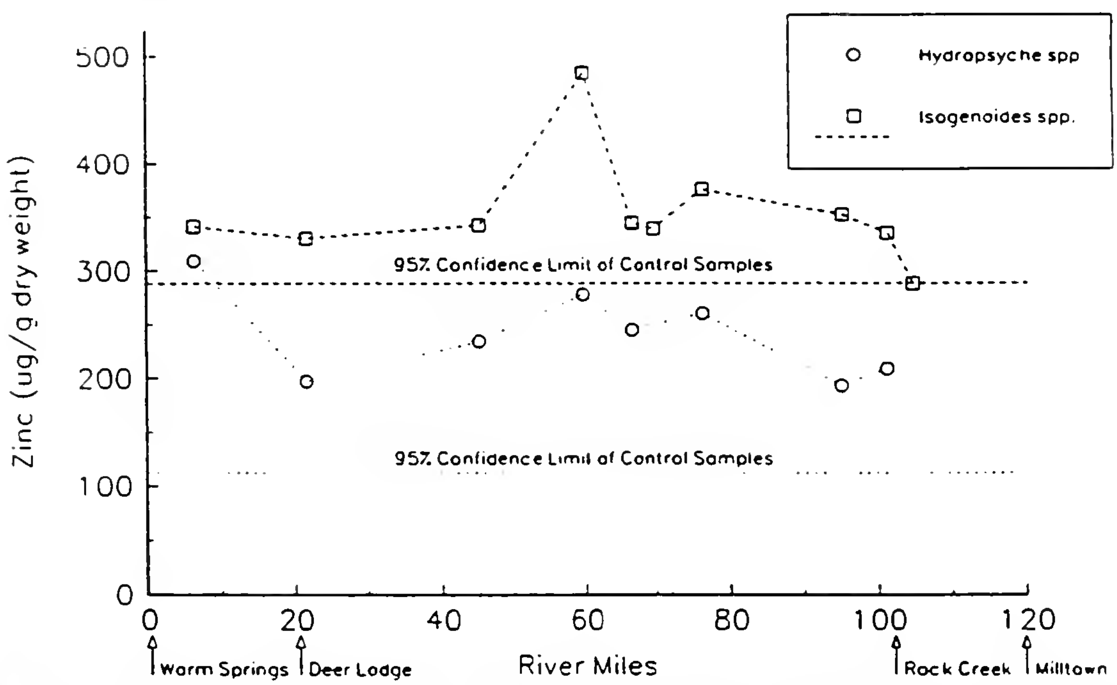

Figure 5-9. Zinc in Field-Collected Invertebrates, Clark Fork River. Source: USGS, 1986.

Mean concentrations in the amphipod *Hyalella azteca* exposed to Clark Fork River and control sediments in a 28-day laboratory test are presented in Table 5-4 and in Figures 5-10 through 5-14. Statistical comparisons were not made between individual Clark Fork River stations and the control station because of the small sample size (n=2 for each sample location). These data confirm that exposure to contaminated Clark Fork River sediments causes accumulation of hazardous substances in macroinvertebrate tissues.

Table 5-4
Mean Concentrations of Hazardous Substances in *Hyalella azteca* Exposed to Clark Fork River and Control Sediments
(n=2 composite samples)

		Metals Concentrations in *H. azteca* (ppm dry weight)				
		Arsenic	Cadmium	Copper	Lead	Zinc
Sediment from the Clark Fork River	At Warm Springs	12.2	0.3	87	7.2	106
	At Deer Lodge	3.8	1.0	124	5.8	80
	At Gold Cr. Bridge	1.9	0.4	127	2.0	79
	At Turah	1.1	0.53	124	5.8	74
Sediment from control areas		0.43	0.14	84	0.4	56

Source: U.S. FWS and University of Wyoming, 1992.

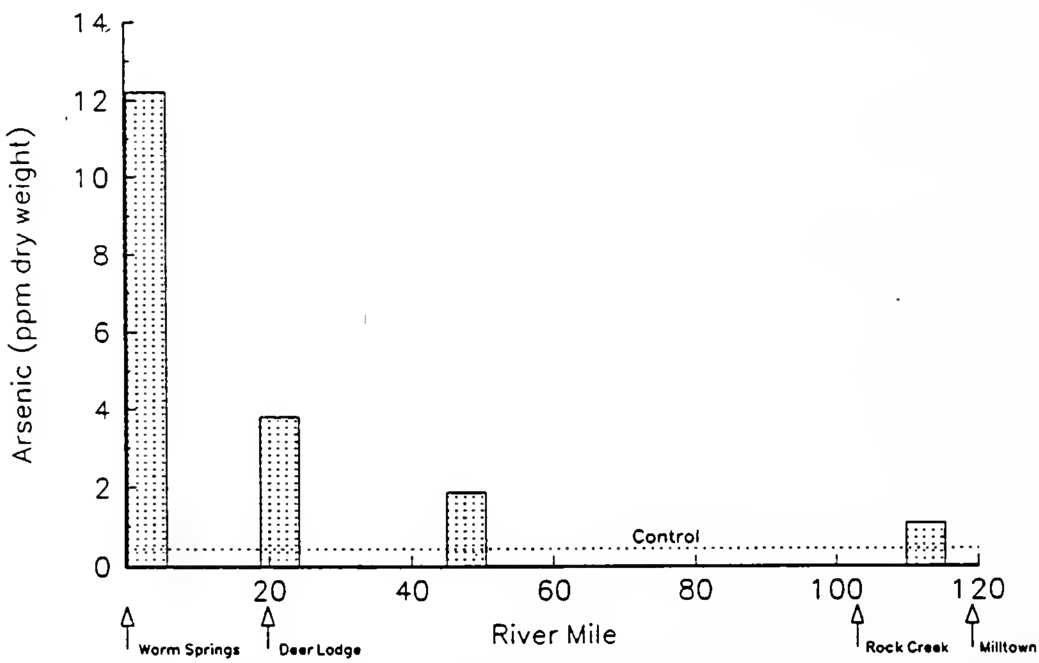

Figure 5-10. Mean Arsenic in Amphipods Exposed To Sediments From Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

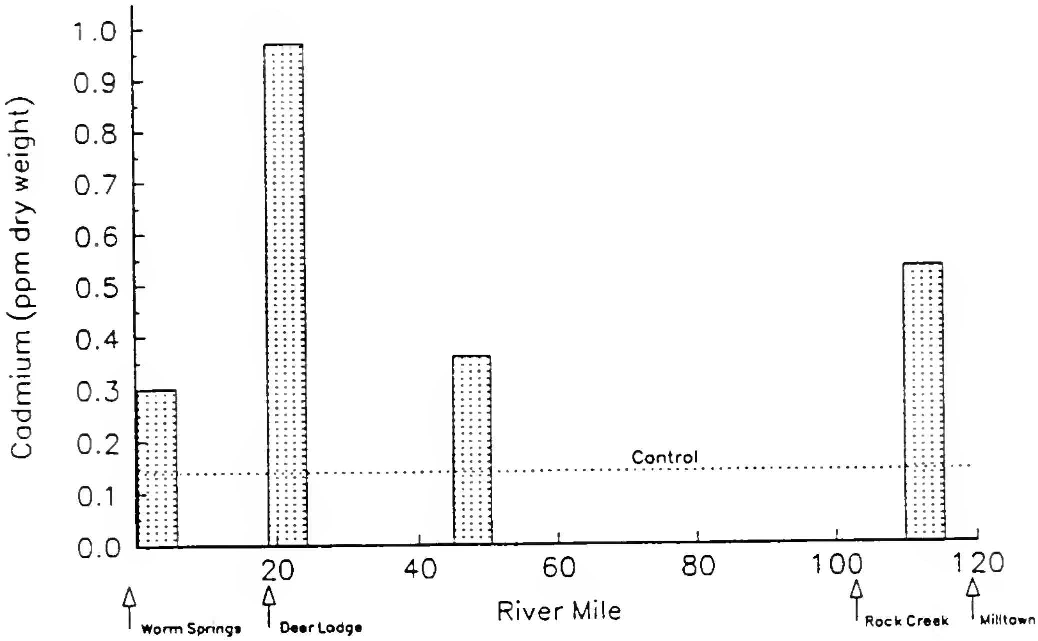

Figure 5-11. Mean Cadmium in Amphipods Exposed To Sediments From Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

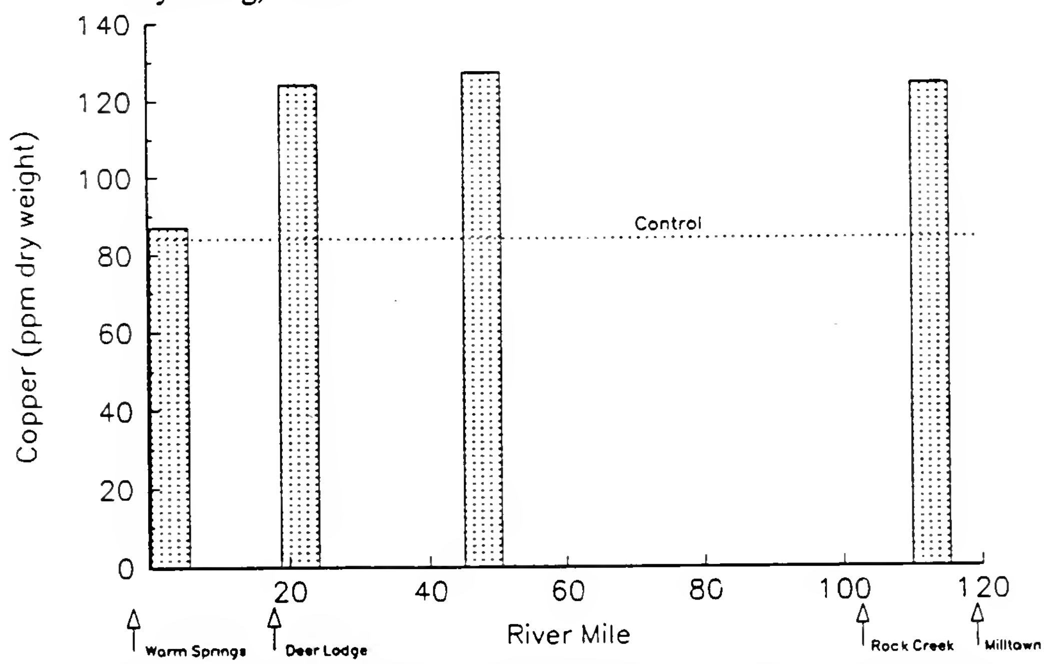

Figure 5-12. Mean Copper in Amphipods Exposed To Sediments From Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

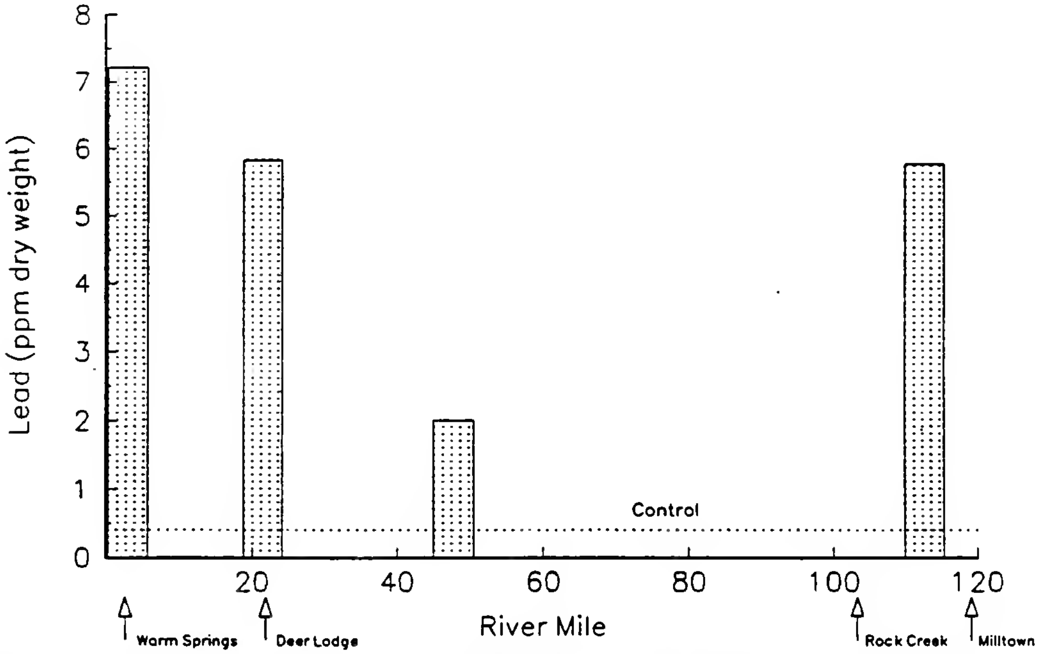

Figure 5-13. Mean Lead in Amphipods Exposed To Sediments From Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

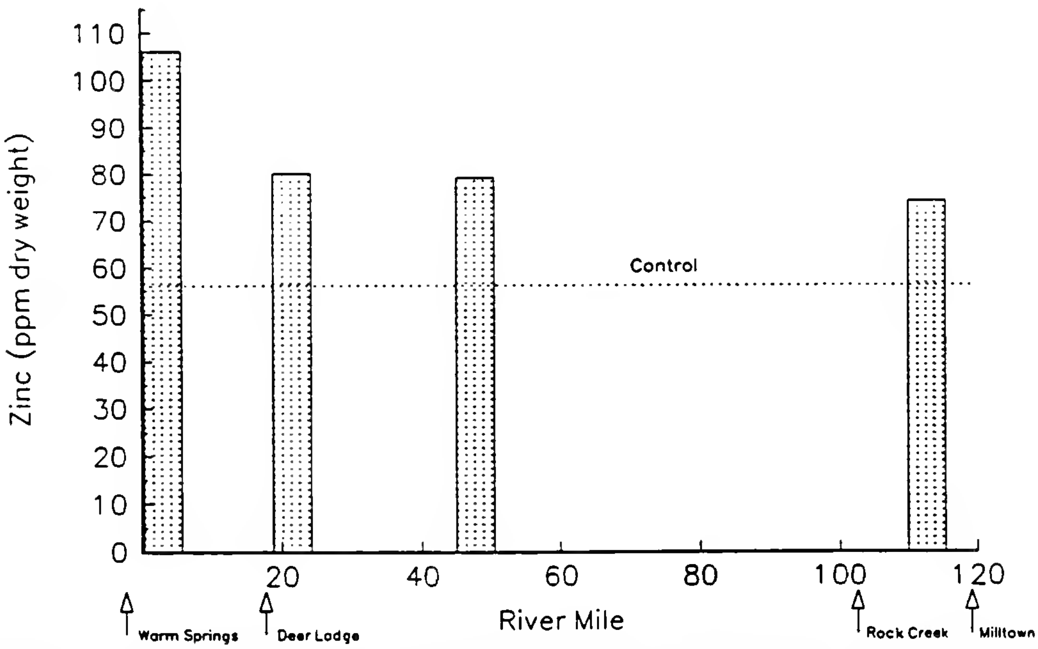

Figure 5-14. Mean Zinc in Amphipods Exposed To Sediments From Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

5.2.3 Conclusions

Several important conclusions can be drawn from these investigations of bioaccumulation in benthic macroinvertebrates:

- Benthic invertebrates from Silver Bow Creek and the Clark Fork River have accumulated hazardous substances at concentrations significantly greater than those from control areas. Therefore, hazardous substances in bed sediments of Silver Bow Creek and the Clark Fork River are bioavailable to aquatic organisms and are not bound to sediment particles in an inert or unavailable form.

- Benthic invertebrates exposed to Silver Bow Creek and Clark Fork River sediments in a controlled laboratory environment accumulate hazardous substances at concentrations well above those in organisms exposed to control area sediments.

- The concentration of hazardous substances accumulated in benthic macroinvertebrates in Silver Bow Creek and the Clark Fork River is correlated with the concentration in the sediments to which they are exposed (Cain *et al.*, 1992). The general decrease in organism tissue concentration with downstream distance in the Clark Fork River corresponds to the decrease in bed sediment concentrations. Variations from this pattern are expected due to the complex interaction of sediment geochemical and biological factors (Axtmann *et al.*, 1990).

5.3 INJURY TO BENTHIC MACROINVERTEBRATES

5.3.1 Injury Definition

Benthic macroinvertebrates are a biological resource. The following definition of injury applies to benthic macroinvertebrates in Silver Bow Creek:

Category of Injury: Death [43 CFR § 11.62 (f)(4)(i)]

- A statistically significant difference can be measured in the total mortality and/or mortality rates between population samples of test organisms placed in exposure chambers containing concentrations of hazardous substances and those in a control chamber. [43 CFR § 11.62 (f)(4)(i)(E).]

Section 5.3.2 presents the results of controlled laboratory studies that document the toxicity of Silver Bow Creek sediments to standard macroinvertebrate test species. In

Section 5.3.3, this observed toxicity to benthic macroinvertebrates is shown to corroborate with field observations of injured benthic macroinvertebrate communities in Silver Bow Creek. Finally, in Section 5.3.4, sediment concentrations of hazardous substances are compared to concentrations expected to impact benthic macroinvertebrate communities.

5.3.2 Laboratory Toxicity Tests

This section describes the results of laboratory toxicity tests using benthic macroinvertebrates. Laboratory toxicity tests using benthic species and sediment chemistry analyses have been used in conjunction with field studies of community structure to corroborate the determination of injury to the benthic community (Chapman *et al.*, 1992). The use of, methods for, and interpretation of sediment toxicity testing using benthic species are fully documented in the scientific literature (e.g., Burton, 1992; Burton, 1991).

In 1991, the U.S. FWS and University of Wyoming collected sediment from Silver Bow Creek one kilometer (0.6 miles) above Warm Springs Ponds (U.S. FWS and University of Wyoming, 1992).[1] Control sediment was collected from Rock Creek. These sediments were used in a series of controlled laboratory toxicity tests, including a 28-day whole-sediment test using the amphipod *Hyalella azteca*, a 14-day whole-sediment test using the midge *Chironomus riparius*, and sediment porewater tests using *Daphnia magna* (48-hour exposure), and the Microtox bioassay[2] (15 minute exposure) (Tables 5-5 and 5-6). In the whole-sediment tests using *Hyalella azteca* and *Chironomus riparius*, measured endpoints were survival, growth, and percent sexual maturation (*Hyalella azteca* only). In the porewater tests, the measured endpoint was survival of *Daphnia magna*. In the Microtox bioassay, the endpoint was luminescence (a measure of biological function). Results for porewater tests are expressed as an EC50 concentration, which is the concentration of the porewater sample (expressed as a percent) which kills 50% of the test organisms (or reduces bioluminescence by 50%, in the case of Microtox). For example, the EC50 value of 17% for *Daphnia magna* means that when *Daphnia magna* are exposed to a mixture of 17% Silver Bow Creek porewater and 83% clean laboratory water, 50% of the organisms die within 48 hours. Overall, the results of the tests showed that Silver Bow Creek sediments were toxic to invertebrates, whereas Rock Creek sediments were not.

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[1] This study was also discussed in Section 5.2.1.

[2] A whole sediment test is a test in which organisms are exposed directly to the sediments, while in a porewater test organisms are exposed to water "squeezed" from the wet sediments. The Microtox test is a rapid laboratory procedure that is used to assess toxicity to aquatic biota.

Table 5-5
Sediment Toxicity Test Results Using Sediment Porewater
Values are EC50s (95% confidence intervals in parentheses) Expressed as a Percentage of the Sample Which Results in 50% Mortality (*Daphnia*) or 50% Reduction in Luminescence (Microtox)

	Control (Rock Creek)	Silver Bow Creek
Daphnia magna (48 hour)	>100*	17 (10-26)
Microtox	>100*	19 (18-20)

* >100% EC50 means that 100% sample water caused less than 50% mortality (*Daphnia*) or 50% reduction in luminescence (Microtox).

Source: U.S. FWS and University of Wyoming, 1992.

Table 5-6
Whole-sediment Toxicity Test Results
(values are means, standard error of the mean in parentheses)

Species	Measured Endpoint	Control Sediments (Rock Creek)	Silver Bow Creek Sediments
Hyalella azteca	% survival	89 (3.8)	48 (9.7)*
H. azteca	length (mm)	4.01 (0.22)	2.85 (0.25)*
H. azteca	% sexually mature males	28 (2.2)	8 (5.0)*
Chironomus riparius	% survival	87 (2.4)	77 (7.2)
C. riparius	length (mm)	13.3 (0.17)	16.0 (0.20)*
Daphnia magna	% survival	100	100

* Statistically different from controls ($p<0.05$).

Source: U.S. FWS and University of Wyoming, 1992.

Whole-sediment test results were compared statistically to determine significant differences between responses to Silver Bow Creek sediments and control sediments. The results show that Silver Bow Creek sediments caused statistically significant adverse changes to *Hyalella azteca* survival, growth, and sexual maturation in whole-sediment tests and *Daphnia magna* survival and Microtox bioluminescence in porewater tests, relative to control sediments (Table 5-6).

No toxicity was observed in 14-day whole-sediment tests using *Chironomus riparius*, but this organism is known to be less sensitive to metals toxicity than *Hyalella azteca* (Ingersoll and Nelson, 1990 and Nelson *et al.*, 1992; as cited in U.S. FWS and University of Wyoming, 1992). Analyses of porewater and sediment chemistry showed that toxicity observed in Silver Bow Creek sediments was strongly associated with elevated concentrations of metals in sediments, sediment porewater, and overlying water (U.S. FWS and University of Wyoming, 1992).

5.3.3 Benthic Community Structure

Effects of metals on benthic macroinvertebrates and community structure have been studied extensively in both field and controlled laboratory studies (for a review, see Clements, 1991). Benthic macroinvertebrates that are known to be sensitive to metals typically are reduced or eliminated in streams contaminated with metals. Specifically, larvae of many of the species in the orders Ephemeroptera (mayflies) and Plecoptera (stoneflies) are known to be particularly sensitive to metals contamination, and the number of individuals or taxa within these orders tends to decrease with increasing metals contamination (Clements, 1991; Leland, *et al.*, 1986 as cited in Clements *et al.*, 1990; Clements *et al.*, 1992). The number of taxonomic groups within the orders Ephemeroptera and Plecoptera (EP) has been used as an index of benthic macroinvertebrate community alteration caused by metals toxicity (Burton, 1992; U.S. EPA, 1989a; U.S. EPA, 1989b; LaPoint, 1984 in Clements *et al.*, 1992). Therefore, statistically significant differences in the number of EP taxa between the assessment area (Silver Bow Creek) and control streams confirm injury to benthic macroinvertebrates caused by exposure to metals.

Silver Bow Creek

At least three investigations of benthic communities in Silver Bow Creek have been conducted in recent years (Chadwick *et al.*, 1986; EA Engineering, 1991; MDHES, 1991). Table 5-7 summarizes the dates, number of stations in Silver Bow Creek, and control streams used in the three studies.

Table 5-7 Summary of Benthic Community Studies on Silver Bow Creek			
Source	**Dates of Sampling**	**Number of Stations in SBC**	**Control Stream**
Chadwick *et al.*, 1986	1984	5	Mill-Willow Bypass
EA Engineering, 1991	1988-89	5 (same locations as above)	Mill-Willow Bypass
MDHES	1986-90	4 (two same as above)	Warm Springs Creek

The number of Ephemeroptera and Plecoptera (EP) taxa in Silver Bow Creek is greatly diminished relative to control areas. Figure 5-15 plots the mean number of EP taxa from each of the three studies against Silver Bow Creek river mile. Control stream results are also included for comparison.

Differences in observed mean number of EP taxa in control streams and Silver Bow Creek were compared using two-sample randomization tests at a significance level of $\alpha = 0.03$ (Manly, 1991). Since the number of EP taxa is relatively constant with downstream distance within Silver Bow Creek and between studies (see Figure 5-15), all Silver Bow Creek stations from all three studies were pooled. Similarly, results from control streams in the three studies were also pooled. The number of EP taxa throughout the length of Silver Bow Creek was found to be significantly lower than in control streams sampled (Table 5-8). Chadwick *et al.* (1986) determined that the observed severe impacts to the benthic community in Silver Bow Creek are not due to lack of suitable habitat. These field observations confirm that benthic macroinvertebrates have been injured throughout the entire length of Silver Bow Creek.

Table 5-8 Results of Two-sample Randomization Test on Number of EP Taxa in Silver Bow Creek vs. Control Streams			
	Number of Samples (pooled over years and locations)	**Mean Number of EP Taxa**	**p-value**
Silver Bow Creek	34	0.6	0.0002
Control streams	9	8.9	

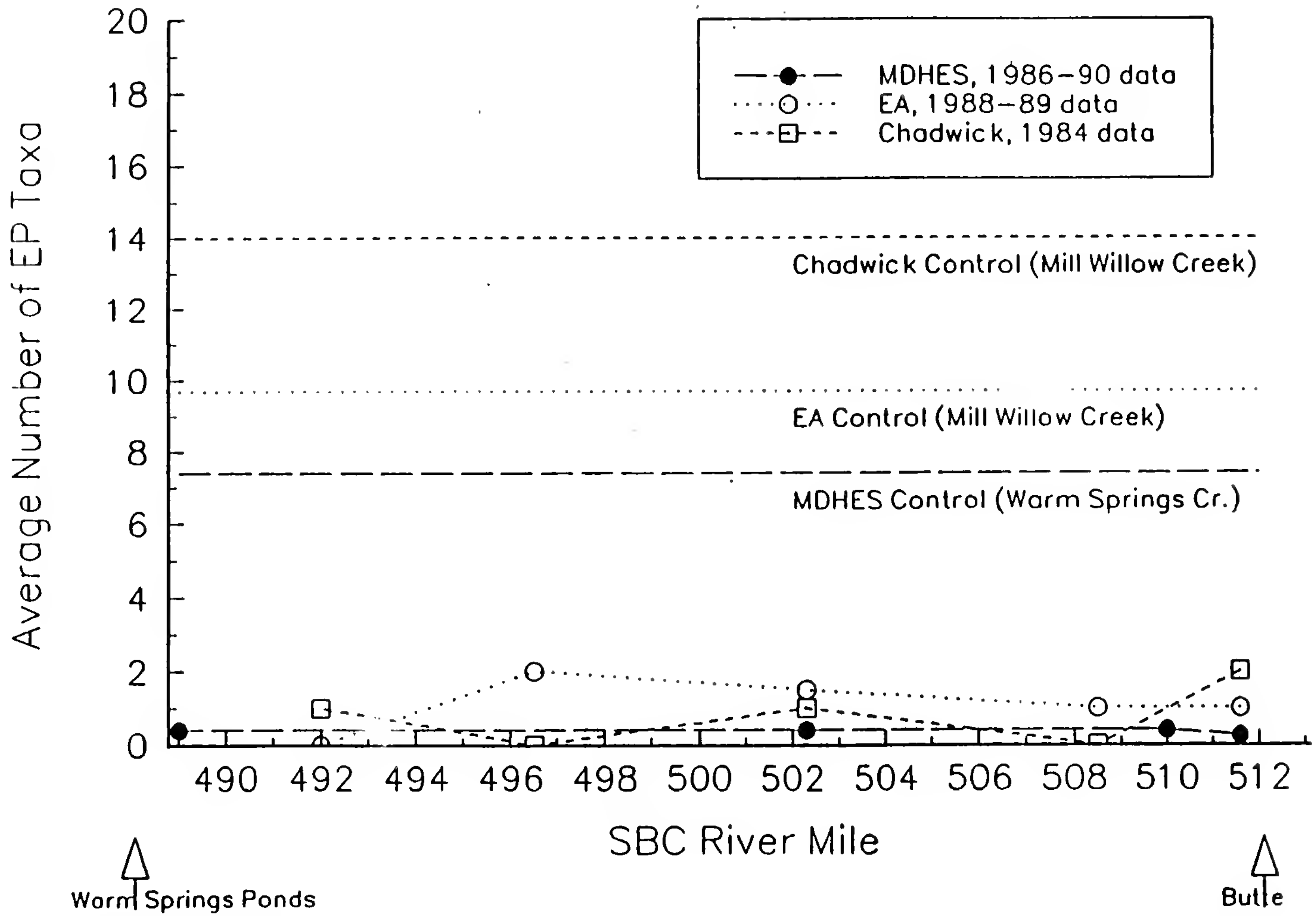

Figure 5-15. Mean Number of EP Taxa vs. Silver Bow Creek River Mile.

Clark Fork River

A similar pattern of reduced macroinvertebrate taxa richness (the number of taxa in the orders Ephemeroptera, Plecoptera, and Tricoptera) has been observed in the Clark Fork River (Figure 5-16). EPT taxa richness compiled by McGuire (1990) increases with downstream distance from the Warm Springs Ponds and matches the pattern of decreasing sediment concentrations with downstream distance (see Chapter 3.0). These data, consistent with observed patterns in Silver Bow Creek, may indicate that the Clark Fork River macroinvertebrates have been injured.

5.3.4 Sediment Threshold Concentrations

In addition to the laboratory and field data presented in the preceding sections, injury to benthic macroinvertebrates from sediment contamination in Silver Bow Creek can also be assessed by comparing contaminant levels to threshold concentrations that have been developed as measures of sediment impacts to benthic communities. The National Oceanic and Atmospheric Administration (NOAA) has used data from their National Status and Trends Program, which monitors aquatic ecosystems across the country, to develop sediment threshold concentrations that represent the likelihood for effects to benthic communities (Long and Morgan, 1990). One of these threshold values is termed the Apparent Effects Threshold (AET), which represents the concentration above which adverse effects to benthic organisms usually or always occurred, based on NOAA's data. Although these AETs integrate data from across the country and from both salt and freshwater environments, they provide valuable "benchmark" information against which Silver Bow Creek sediments can be compared.

The Ontario Ministry of the Environment has also developed sediment threshold concentrations for contaminants. Their thresholds are developed from field-based data on the relationship between sediment contaminant concentrations and benthic communities (Persaud *et al.*, 1991). These thresholds are developed primarily from data for freshwater systems. The Severe Effects Threshold (SET) represents the contaminant concentration in sediments at which "pronounced disturbance of the sediment-dwelling community can be expected" (Persaud *et al.*, 1991). It is "the sediment concentration of a compound that would be detrimental to the majority of benthic species" (Persaud *et al.*, 1991). This SET, and the NOAA AET, thus are thresholds for individual contaminants above which *major* impacts to benthic communities can be expected. NOAA AETs and Ontario SETs are given in Table 5-9 for arsenic, cadmium, copper, lead, and zinc.

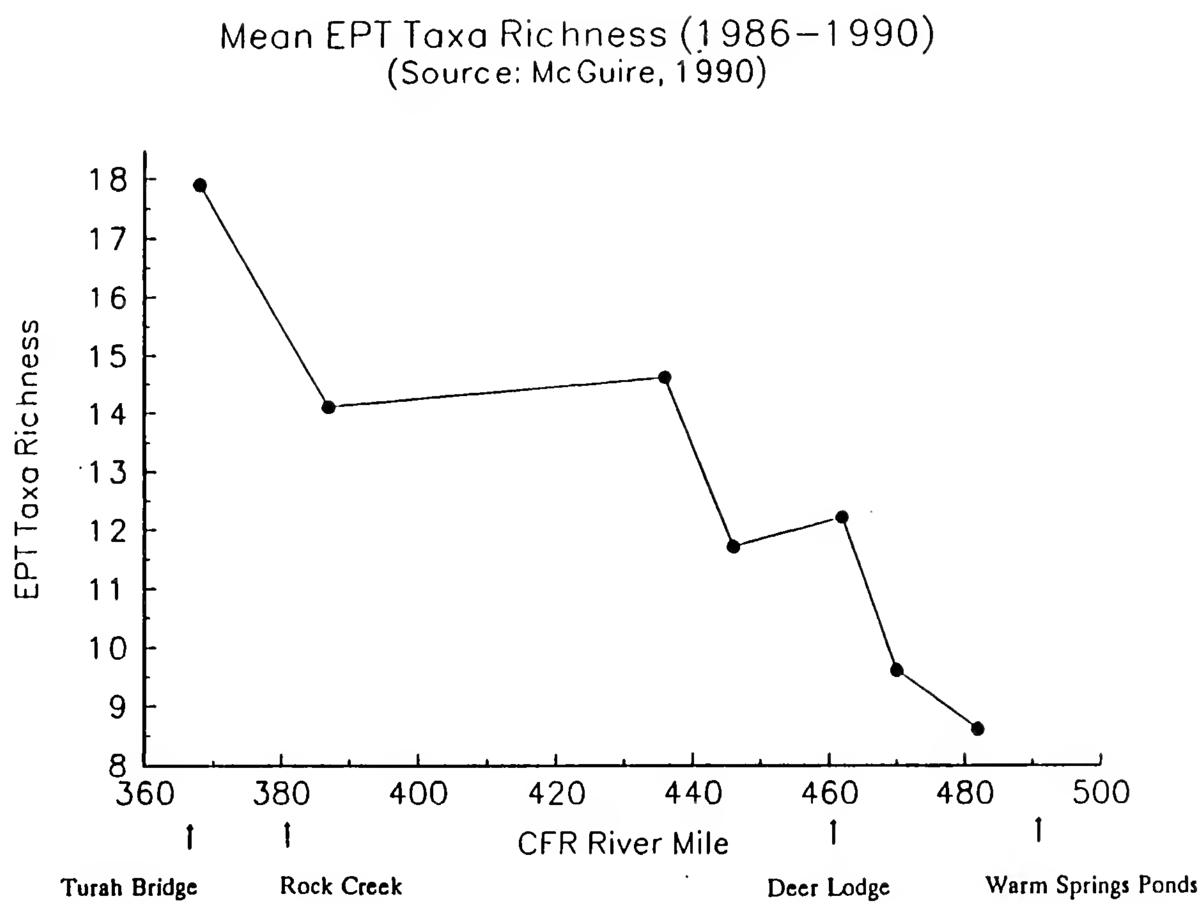

Figure 5-16. Benthic Macroinvertebrate (EPT) Taxa Richness vs. Clark Fork River Mile.

Table 5-9
NOAA's AETs and Ontario's Severe Effects Thresholds for Sediments

	NOAA Apparent Effects Threshold (AET) (ppm dry wt.)	Ontario's Severe Effects Threshold (SET) (ppm dry wt.)
Arsenic	50	33
Cadmium	5	10
Copper	300	110
Lead	300	250
Zinc	260	820

Figures 5-17 through 5-21 compare the concentration ranges for arsenic, cadmium, copper, lead, and zinc with their AETs and SETs in Silver Bow Creek and control streams (Rock Creek, Ruby River, and Gold Creek). Two different Silver Bow Creek mean concentrations are plotted: mean concentrations in bulk, or total, sediments (PTI, 1989), and mean concentrations in fine-grained (<63 μm) sediments (Essig and Moore, 1992).

These figures show that every Silver Bow Creek fine-grained sediment sample contained arsenic, cadmium, copper, lead, and zinc above the applicable AET and SET; mean concentrations are orders of magnitude greater than AETs and SETs for these hazardous substances. Mean bulk concentrations of arsenic, copper, and zinc also exceed both the AET and SET. Although *mean* bulk concentrations of cadmium and lead are below both thresholds, concentrations of these hazardous substances have been measured that exceed the thresholds.

Figures 5-22 through 5-24 compare concentrations of arsenic, copper, and zinc with their AETs and SETs for the Clark Fork River. As with Silver Bow Creek, all copper concentrations in the Clark Fork River exceeded both thresholds. Arsenic and zinc concentrations exceeded both thresholds at the upper and middle Clark Fork River sites (see Chapter 3.0 for description of river reaches). At the lower Clark Fork River site, zinc and arsenic values exceeded the SET, the mean zinc concentration exceeded the AET, and some arsenic concentrations exceeded the AET.

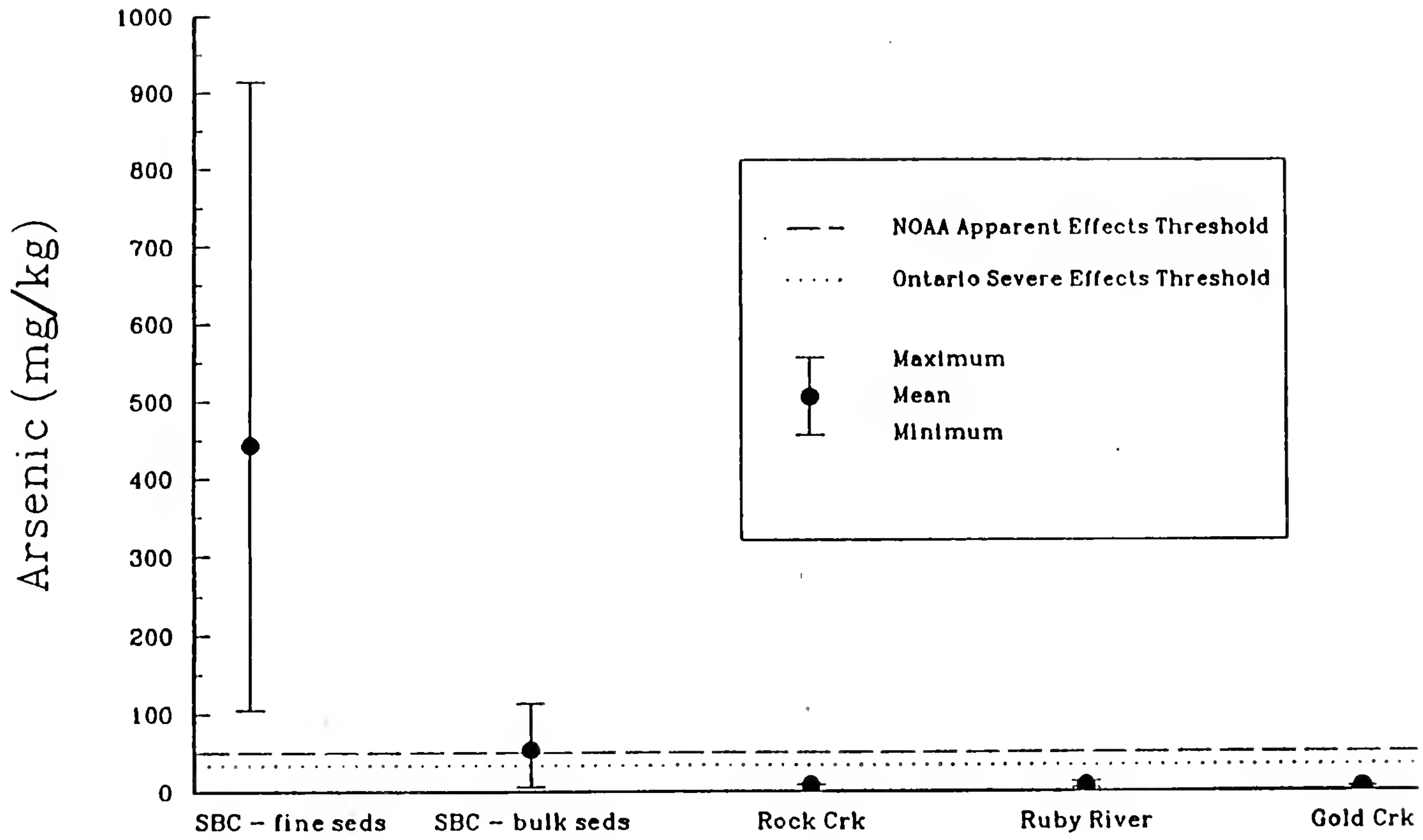

Figure 5-17. Arsenic Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared With Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

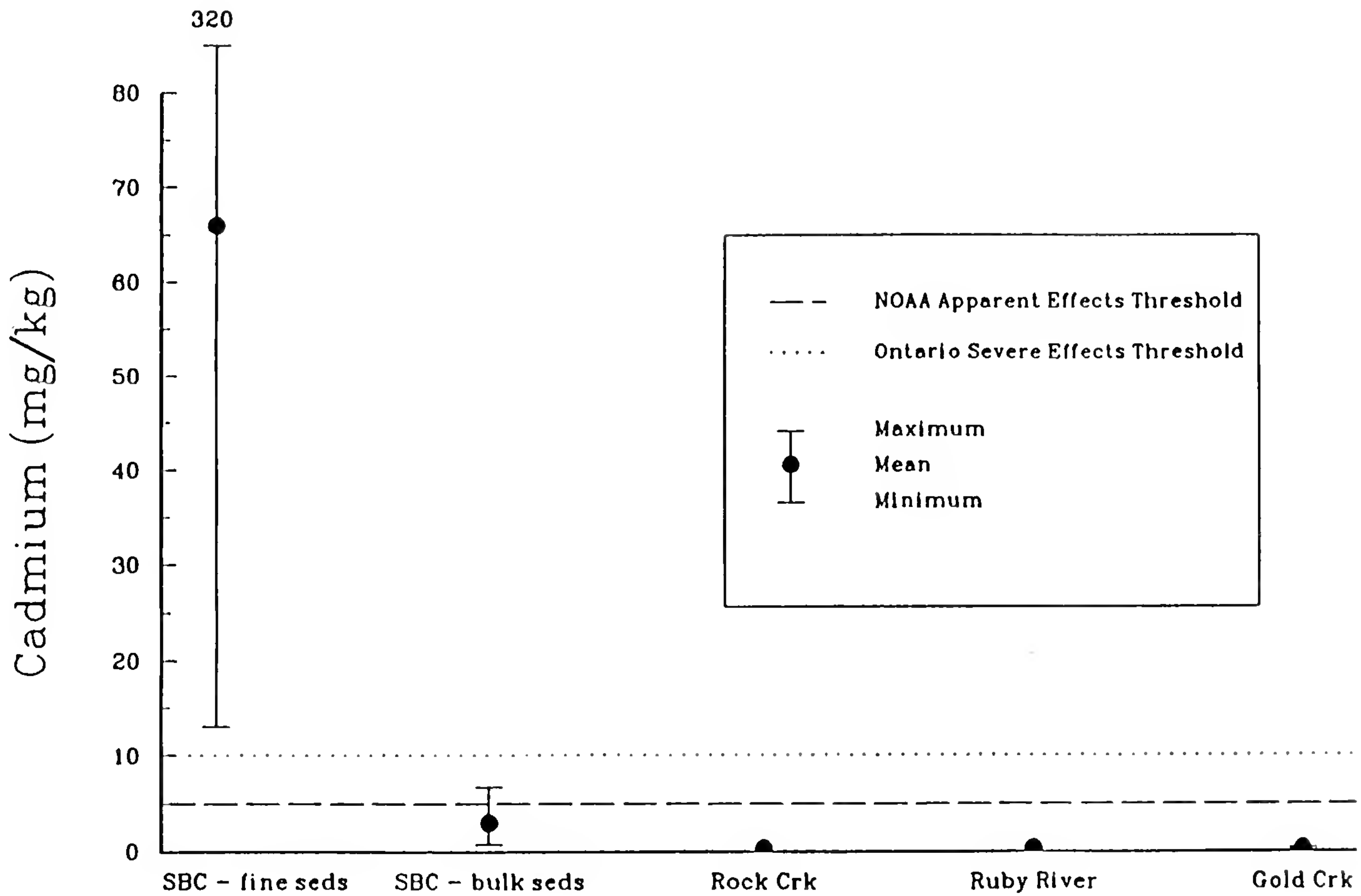

Figure 5-18. Cadmium Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared With Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

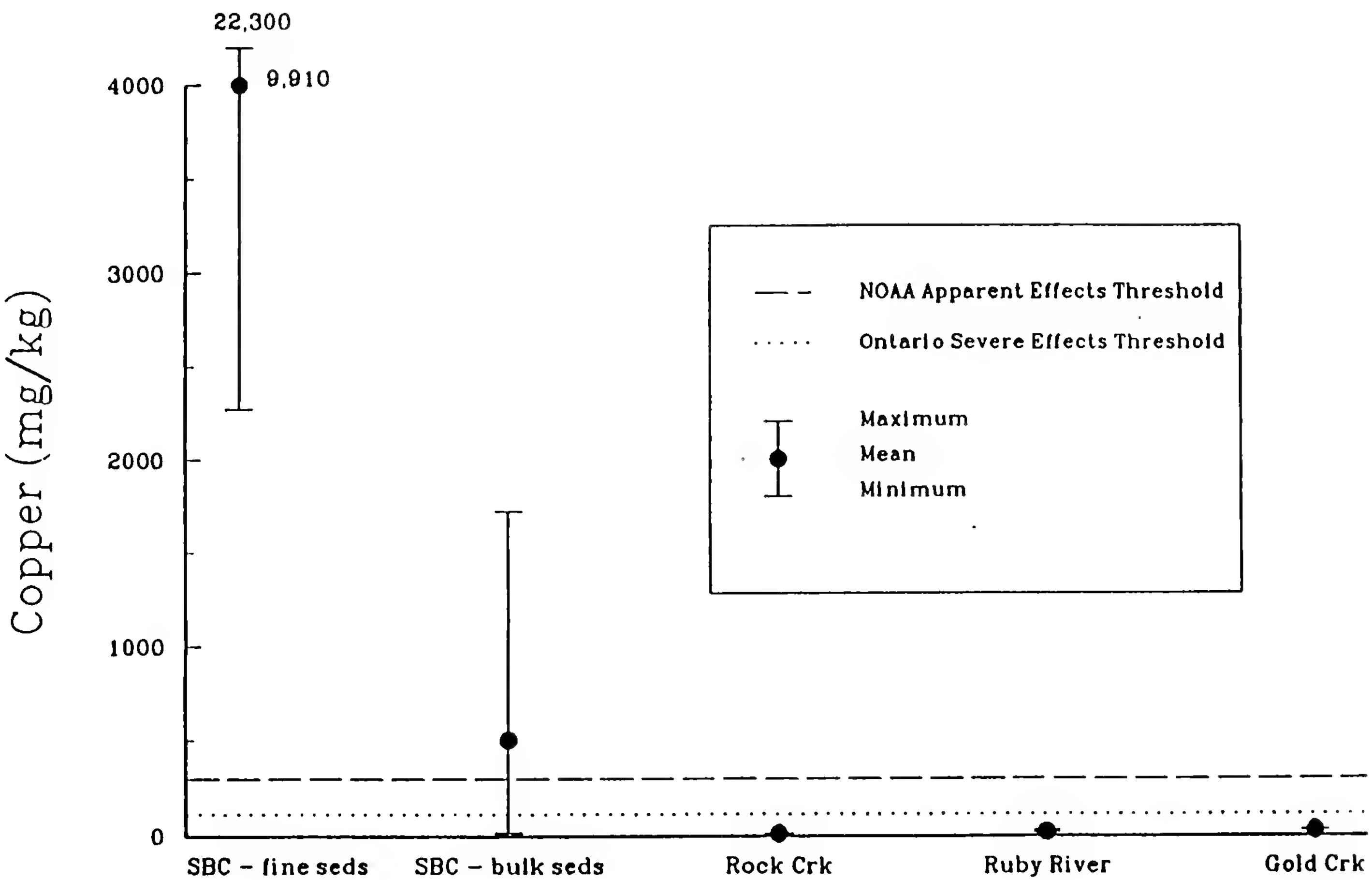

Figure 5-19. Copper Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared With Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

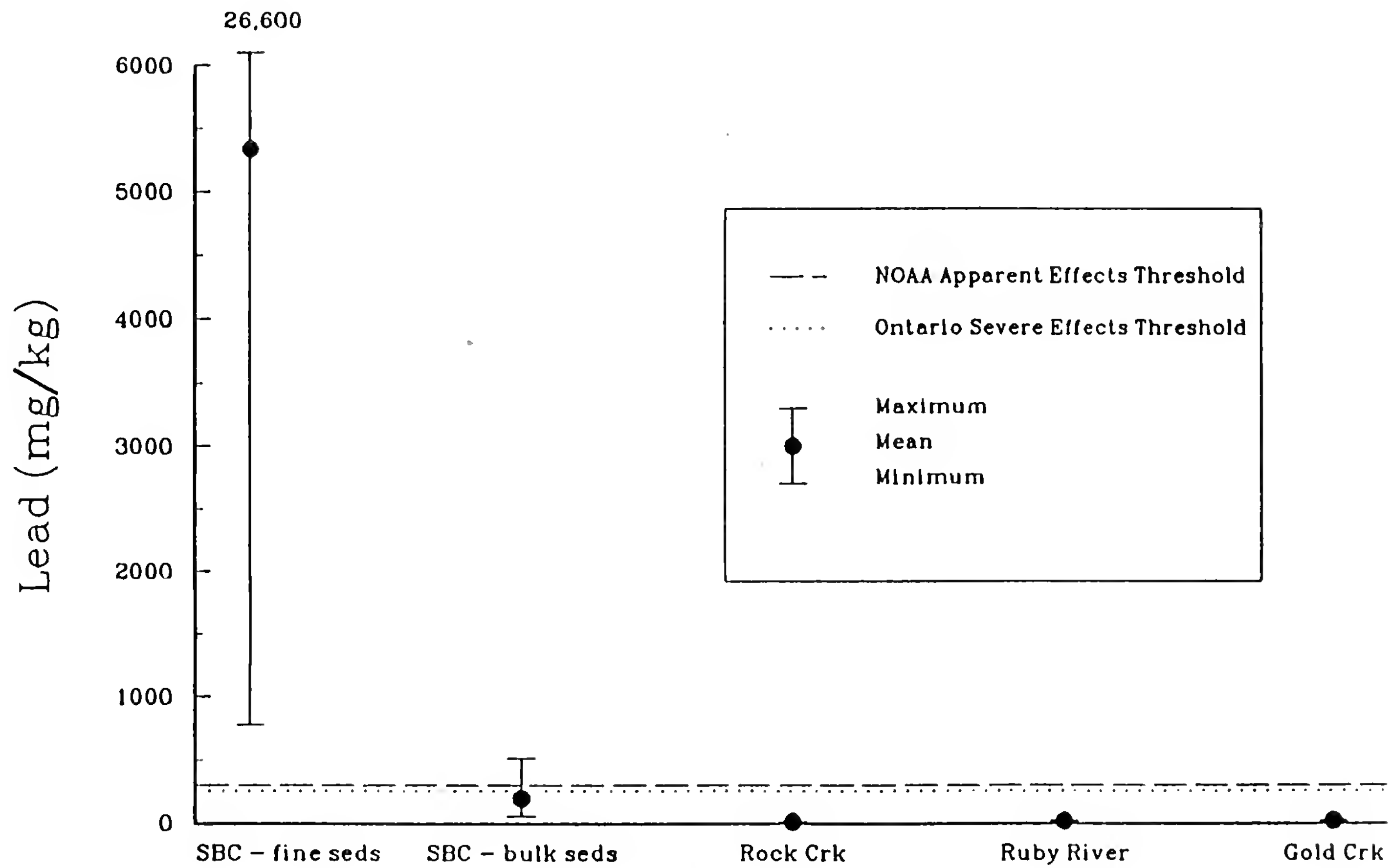

Figure 5-20. Lead Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared With Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

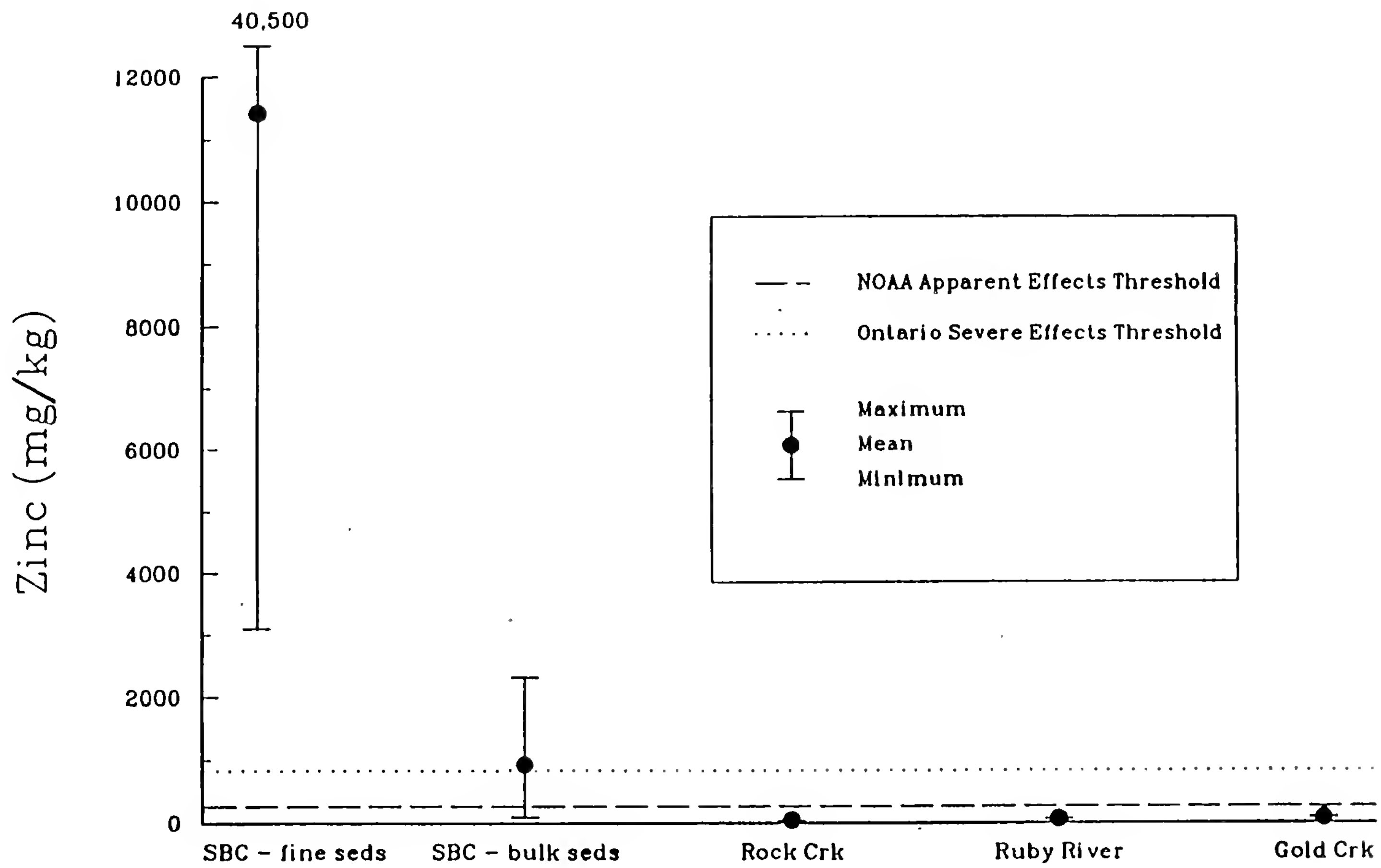

Figure 5-21. Zinc Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared With Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

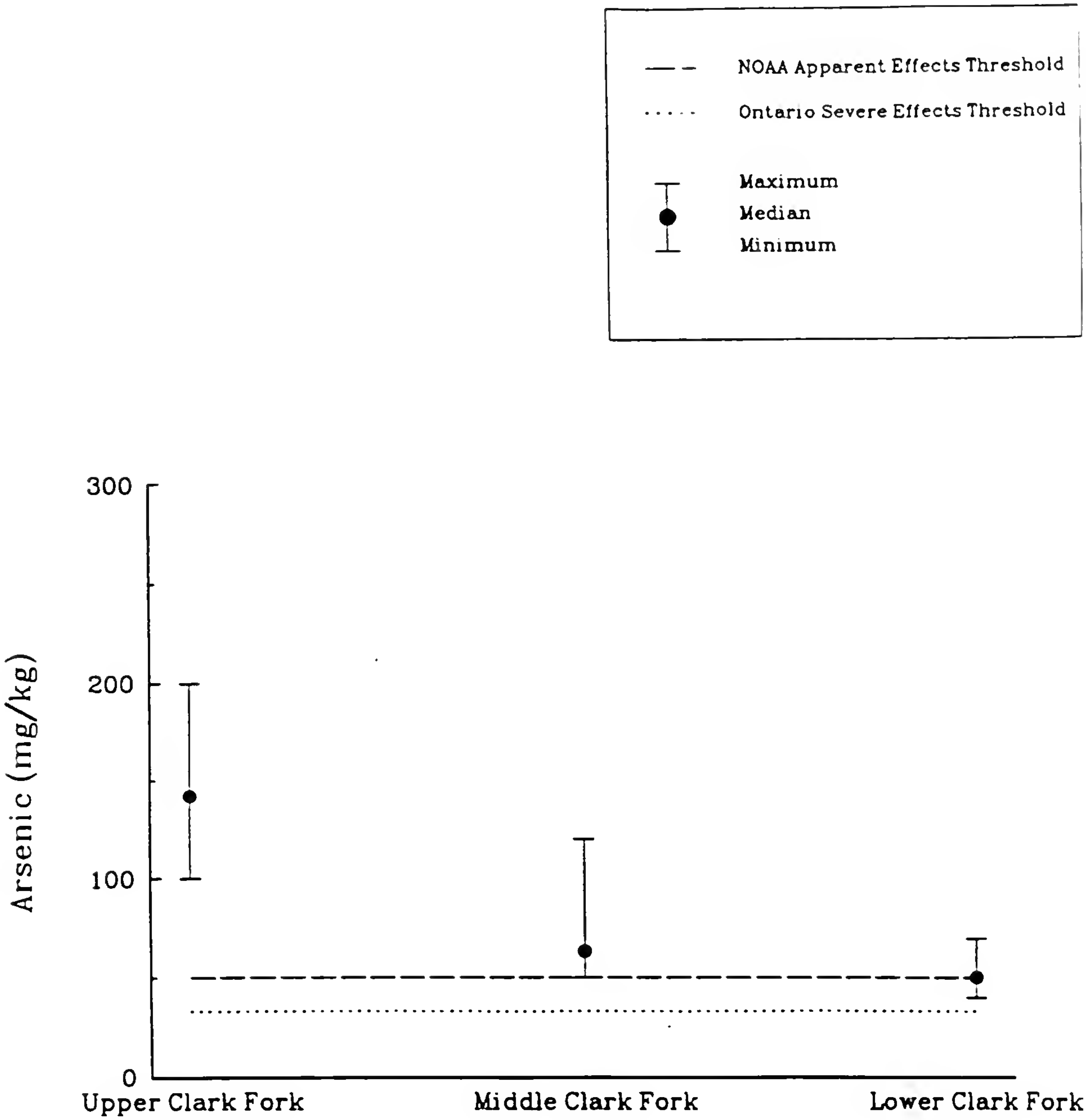

Figure 5-22. Concentrations of Arsenic in Clark Fork River Bed Sediments Compared with Sediment Threshold Concentrations. Source: Essig and Moore, 1992.

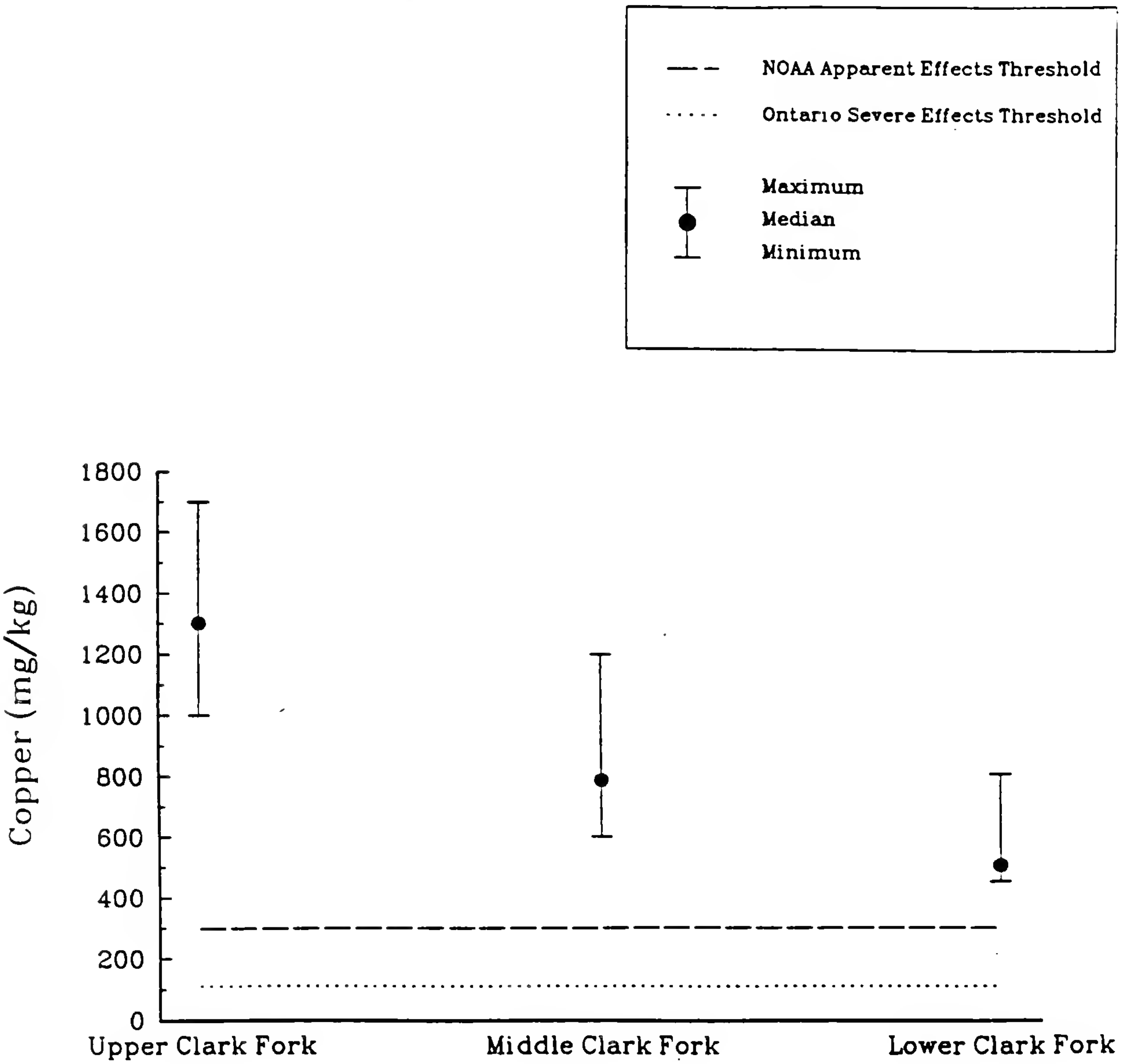

Figure 5-23. Concentrations of Copper in Clark Fork River Bed Sediments Compared with Sediment Threshold Concentrations. Source: Essig and Moore, 1992.

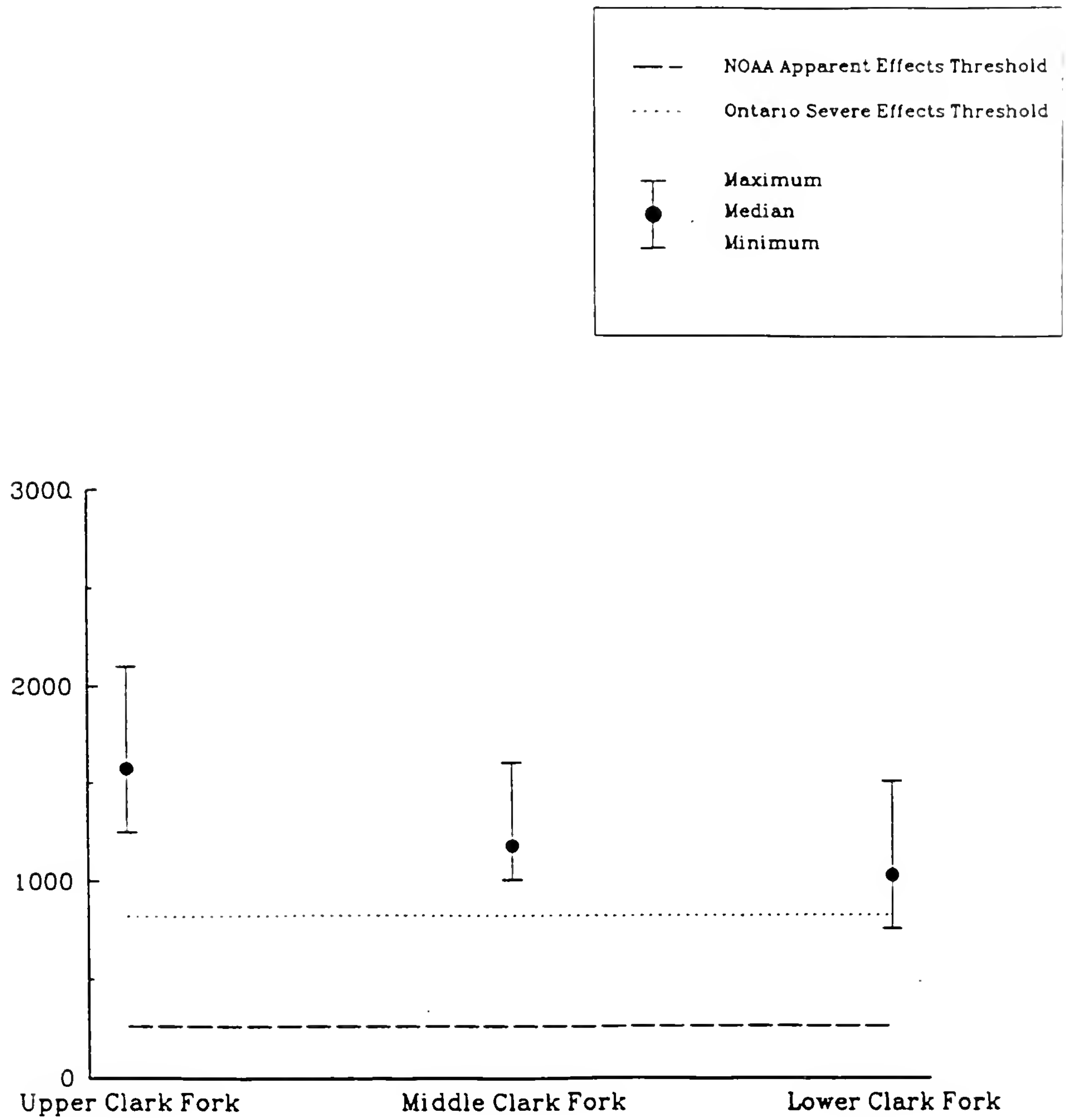

Figure 5-24. Concentrations of Zinc in Clark Fork River Bed Sediments Compared with Sediment Threshold Concentrations. Source: Essig and Moore, 1992.

In conclusion:

- Laboratory toxicity tests confirm that exposure to Silver Bow Creek sediments (which have been shown to contain extremely elevated concentrations of hazardous substances) caused both mortality and reduced growth in macroinvertebrate test species.

- Field studies in Silver Bow Creek demonstrate reductions in invertebrate taxa known to be sensitive to hazardous substances. These reductions occur throughout the length of Silver Bow Creek, and may occur in the Clark Fork River.

- Bed sediments of Silver Bow Creek contain hazardous substances at concentrations above which major effects to benthic communities are expected. Exceedence of the AET or SET for any single metal indicates that benthic communities are expected to be severely impacted; in Silver Bow Creek, all metals exceeded the thresholds. In the Clark Fork River, bed sediments exceeded thresholds for copper, zinc, and arsenic.

5.4 INJURY QUANTIFICATION: SPATIAL AND TEMPORAL EXTENT OF INJURY

As described above, benthic macroinvertebrates presently are injured throughout the length of Silver Bow Creek. Previous investigations have shown that historically, macroinvertebrate populations have been injured to an even greater extent. The earliest available surveys of macroinvertebrates in Silver Bow Creek from the late 1950s found no benthic macroinvertebrates or only one pollution-tolerant species in the creek (Averett, 1961; Spindler, 1959). Additional investigations in the early 1970s also were unable to locate any invertebrates in Silver Bow Creek (Chadwick & Associates, 1985). It is likely that Silver Bow Creek did not support any invertebrates for decades before the first surveys in the 1950s, as well as during the period between the surveys of the 1950s and early 1970s; no water quality improvement measures were in place during these times that would have reduced contamination in Silver Bow Creek.

The benthic community of Silver Bow Creek did not begin to recover immediately after improvement in wastewater treatment that reduced metals loadings at the Weed Concentrator in 1972. Rather, surveys in 1973 and 1974 still showed no invertebrates, and not until 1975 were any benthic organisms found in Silver Bow Creek (Chadwick *et al.*, 1986). Recovery has proceeded slowly since then (Chadwick *et al.*, 1986).

Natural recovery of Silver Bow Creek will proceed extremely slowly. Creek floodplains contain large amounts of tailings, wastes, and soils contaminated with hazardous

substances (see Chapter 2.0). These sources will contribute hazardous substances to the Creek for many years if not restored (Johnson and Schmidt, 1988; MultiTech, 1987; Nimick, 1990). Contaminated groundwater continues to discharge hazardous substances, including metals, to Silver Bow Creek near Lower Area One (see Chapter 4.0). Hazardous substances in the sediments of Silver Bow Creek are not naturally degraded or decomposed. Furthermore, the only natural recovery process, which is dilution by cleaner sediments or fluvial transport downstream, will be limited since the Silver Bow Creek watershed is highly contaminated by a wide variety of hazardous substances, and relatively little clean sediments or soils are available in the watershed for dilution.

In conclusion, benthic macroinvertebrates have been injured as a result of exposure to contaminated sediments. Any natural recovery of sediments in Silver Bow Creek, and hence macroinvertebrates, will take hundreds to thousands of years. As described by the U.S. EPA (1992) "the recovery period (for the aquatic ecosystem in the Lower Area One) has virtually been eliminated."

5.5 BENTHIC MACROINVERTEBRATE INJURY SUMMARY

The benthic macroinvertebrate community throughout Silver Bow Creek is injured. The number of EP taxa, an index for measuring impacts to benthic communities from metals contamination, is significantly reduced relative to control streams. Silver Bow Creek sediments are toxic to a variety of organisms in controlled laboratory experiments. Concentrations of hazardous substances throughout Silver Bow Creek are well above threshold levels where severe adverse impacts to benthic macroinvertebrates are expected. Based on these results, the benthic macroinvertebrate resource is injured for the entire length of Silver Bow Creek. Data suggest that benthic macroinvertebrates may be injured in the Clark Fork River also.

Historical sampling of invertebrate communities shows that the benthic macroinvertebrates have been injured for many decades. Natural recovery of the macroinvertebrate community will proceed extremely slowly.

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6.0 FISHERIES

6.1 INTRODUCTION

The previous three chapters of this report (Chapter 3.0 — Sediments, Chapter 4.0 — Surface Water and Chapter 5.0 — Macroinvertebrates) have shown that fish habitat (i.e., surface water and sediments) and prey (benthic macroinvertebrates) in Silver Bow Creek and the Clark Fork River have been exposed to, and/or injured by, hazardous substances released from the Butte and Anaconda areas and re-released via pathway mechanisms. Both bulk and fine-grained sediments are contaminated with the hazardous substances arsenic, cadmium, copper, lead, and zinc in Silver Bow Creek and the Clark Fork River. These substances are biologically available to both fish and macroinvertebrates and serve as a principal pathway to macroinvertebrates. Macroinvertebrates have been injured throughout the length of Silver Bow Creek, and data suggest that they may be injured in the Clark Fork River. In addition, macroinvertebrates throughout Silver Bow Creek and the Clark Fork River contain elevated concentrations of hazardous substances and thus serve as a pathway to fish. Finally, hazardous substances have injured surface waters of both Silver Bow Creek and the Clark Fork River.

This chapter contains the assessment of injury to fishery resources of the Clark Fork River and Silver Bow Creek. This assessment focuses on *trout* because of their significant recreational and non-use values; the State has not assessed injury to all species of fish. Thus, for the purposes of this report, "fishery resources" are defined as trout of various species.

Injuries to fishery resources in Silver Bow Creek and the Clark Fork River have been documented for many years. Historically, the Clark Fork River was contaminated with hazardous substances to the extent that no fish and few invertebrates were seen in the river from the late 1800s until the mid 1950s (Spindler, 1959; Johnson and Schmidt, 1988). Casne *et al.* (1975) reported a complete lack of biota in the Clark Fork between Warm Springs Ponds and Dempsey, with the exception of two pollution-tolerant invertebrates, between 1970 and 1972. The trout population in the upper Clark Fork between Butte and Rock Creek is composed almost exclusively of brown trout (*Salmo trutta*) (Knudson, 1984; Johnson and Schmidt, 1988). Rainbow trout (*Oncorhynchus mykiss*) rarely occur upstream of Rock Creek, over 100 river miles downstream of the Warm Springs Ponds; native bull trout (*Salvelinus confluentus*) and westslope cutthroat trout (*Salmo clarki*) have been virtually eliminated from the Clark Fork River (Knudson, 1984; Montana DNR, 1988). In contrast, the nearby Blackfoot River supports populations of brown, rainbow, cutthroat, bull, and brook trout (*Salvelinus fontinalis*) (Knudson, 1984).

This chapter describes the nature and extent of injuries to fish in Silver Bow Creek and the Clark Fork River Basin. **Section 6.2, Pathway Determination**, identifies contaminated

surface water, sediments, and macroinvertebrates as the pathways by which the fish of the Upper Clark Fork River Basin are exposed to hazardous substances. **Section 6.3, Injury Definition**, identifies the types of injuries to the fisheries resource; **Section 6.4, Injury Determination**, presents information showing that the injuries to fish have resulted from exposure to the hazardous substances in the upper Clark Fork River Basin, specifically: 1) fishkills have been documented in the Clark Fork River (Section 6.4.1); 2) *In situ* bioassays performed in Silver Bow Creek and the Clark Fork River have demonstrated trout mortality (Section 6.4.2); 3) laboratory exposure to hazardous substances found in the Clark Fork River causes trout mortality (Sections 6.4.3 and 6.4.4); 4) trout avoid water containing hazardous substances at concentrations that occur in Silver Bow Creek and the Clark Fork River (Section 6.4.5); 5) ingestion of contaminated macroinvertebrates from the Clark Fork River causes mortality and growth reductions in trout (Section 6.4.6); and 6) trout suffer physiological health impairments, including growth reductions, as a result of exposure to hazardous substances in Clark Fork River surface water and macroinvertebrates (Section 6.4.7). Finally, **Section 6.5, Injury Quantification**, quantifies injuries to fish in terms of trout population and biomass reductions in Silver Bow Creek and the Clark Fork River relative to baseline conditions.

6.2 PATHWAY DETERMINATION

The purpose of the pathway determination is to identify the route or media by which hazardous substances have been transported from their sources to the fish of the upper Clark Fork River Basin. The sources of hazardous substances in the basin are detailed in Chapter 2.0, and mechanisms by which the hazardous substances are transported from the sources to the surface water and sediments of Silver Bow Creek and the Clark Fork River are described in Chapter 3.0 (Sediments) and Chapter 4.0 (Surface Water). Chapter 5.0 (Benthic Macroinvertebrates) presented information of exposure to and uptake of hazardous substances by invertebrates that serve as prey for trout. Two distinct pathways result in exposure of fish to hazardous substances (Figure 6-1):

- **Surface Water Pathway.** This pathway involves direct contact by the fish with hazardous substances in surface water. The contact mechanism involves exposure to hazardous substances in water that flows across the gills or, in the case of avoidance behaviors, olfactory sensation of hazardous substances in water.

- **Food Chain/Sediments Pathway.** This pathway involves contact with hazardous substances through consumption of contaminated food. Benthic macroinvertebrates accumulate hazardous substances from contaminated sediments (see Chapter 5.0). These invertebrates, when consumed by fish, serve as a dietary exposure pathway.

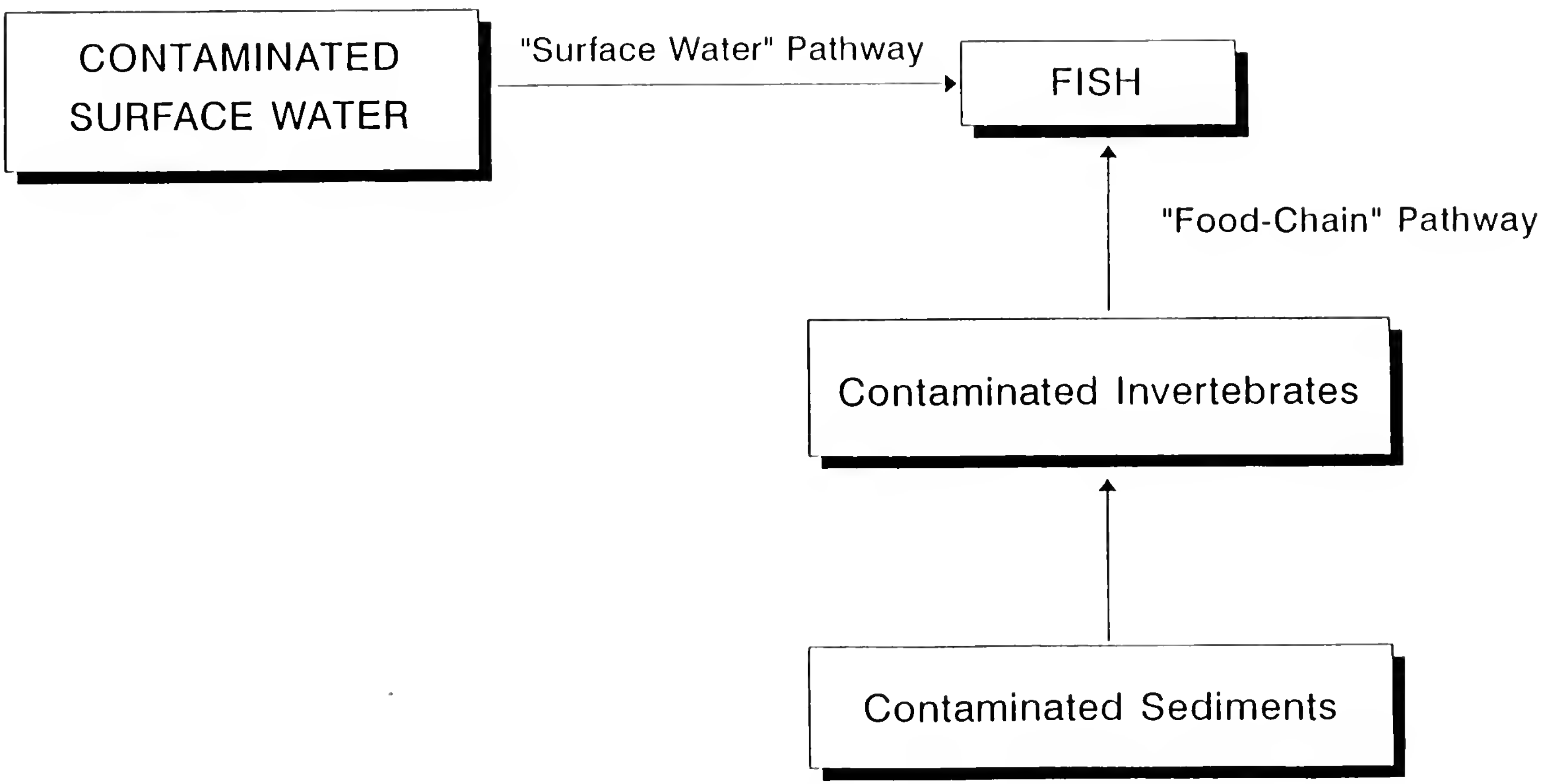

Figure 6-1. Pathways by which Fish are Exposed to Hazardous Substances.

These two principal pathways are described briefly below in Sections 6.2.1 and 6.2.2. Data demonstrating the presence of hazardous substances in surface water, sediments, and benthic macroinvertebrates are presented in Chapters 3.0 through 5.0.

6.2.1 Surface Water Pathway

A discussion of the sources, transport pathways, and rate of transport of hazardous substances in surface water can be found in Chapters 2.0 and 4.0. A brief summary is included in this section.

Surface water resources of Silver Bow Creek and the Clark Fork River have been exposed to and injured by the hazardous substances cadmium, copper, lead, and zinc. In Silver Bow Creek, concentrations of copper and zinc have exceeded both acute and chronic ambient water quality criteria in virtually 100% of all samples collected. Chronic criteria have been exceeded regularly for lead and cadmium.

In the Clark Fork River, copper concentrations have regularly exceeded acute and chronic criteria, although the frequency of exceedences, as well as the measured concentrations, are lower than in Silver Bow Creek. Concentrations of both zinc and lead have also exceeded water quality criteria.

Hazardous substances have been and continue to be carried downstream to the Clark Fork River by Silver Bow Creek and the Warm Springs Ponds discharge. The hazardous substances are transported in surface waters in both dissolved and particulate forms. Particulate forms are transported as tailings, other mining wastes, and as contaminated soils and sediments. Large amounts of these hazardous substance-containing materials have been carried downstream by the Clark Fork River and deposited in bed sediments and along banks, floodplains, and in the Milltown Reservoir. Floodplain deposits and riverside tailings act as continuous secondary sources to Clark Fork bed sediments and surface waters through erosion, runoff, and leaching of soluble substances into surface water or groundwater and subsequent deposition to sediments.

6.2.2 Sediment/Food Chain Pathway

The sediments of Silver Bow Creek and the Clark Fork River from the Warm Springs Ponds to Milltown are highly contaminated with the hazardous substances arsenic, cadmium, copper, lead, and zinc as a result of large-scale mining and mineral processing operations in the Butte and Anaconda areas. As shown in Chapter 3.0, median concentrations of copper, cadmium, zinc, lead and arsenic in Silver Bow Creek fine-grained sediments are approximately 500, 150, 150, 100 and 80 times greater than baseline conditions, respectively. In Clark Fork River sediments, median concentrations

of copper, cadmium, zinc, arsenic, and lead are approximately 65, 35, 27, 20 and 11 times greater than baseline concentrations, respectively.

Benthic macroinvertebrates live in and on bed sediments and thus are exposed directly to hazardous substances contained in sediments. These organisms play essential roles in aquatic ecosystems, including serving as a primary food source for trout. As shown in Chapter 5.0, benthic macroinvertebrates contain significantly elevated concentrations of the hazardous substances arsenic, cadmium, copper, lead, and zinc, relative to baseline conditions. In addition, Chapter 5.0 demonstrates that the hazardous substances contained in sediments of Silver Bow Creek and the Clark Fork River are biologically available to aquatic organisms, that macroinvertebrates have been found to accumulate hazardous substances in both field and controlled laboratory sediments, and that concentrations of hazardous substances in macroinvertebrates are correlated with the concentrations in sediments to which they have been exposed.

Thus, contaminated sediments act as the principal pathway of hazardous substances to benthic macroinvertebrates which, in turn, serve as a pathway to fish via food chain exposures.

6.3 INJURY DEFINITION

The following section identifies the injuries to fishery resources resulting from hazardous substances in Silver Bow Creek and the Clark Fork River, as well as describing approved methodologies for determining these injuries.

An injury to fish has resulted if one or more of the following changes has occurred: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62 (f)(1)]. The following types of injury — all of which have been determined by the U.S. DOI to have met the acceptance criteria for injury — have been assessed by the State:

Category of Injury : Death [43 CFR § 11.62 (f)(4)(i)]

- A significant increase in the frequency or numbers of dead or dying fish can be measured in fishkill investigations [43 CFR § 11.62 (f)(4)(i)(B)].

- A statistically significant difference can be measured in the total mortality and/or mortality rates in *in situ* bioassays [43 CFR § 11.62 (f)(4)(i)(D)].

- A statistically significant difference can be measured in the total mortality and/or mortality rates between population samples of test organisms placed

in laboratory exposure chambers containing concentrations of hazardous substances and those in a control chamber [43 CFR § 11.62 (f)(4)(i)(E)].

Category of Injury : Behavioral Abnormalities [43 CFR § 11.62 (f)(4)(iii)]

- A statistically significant difference can be measured in the frequency of avoidance behavior in population samples of fish placed in a testing chambers with equal access to water containing... a hazardous substance and water from the control area [43 CFR § 11.62 (f)(4)(iii)(B)].

Category of Injury: Reduced Growth and Health Impairment

Growth is considered to be an endpoint, or indicator, of effects on reproduction and toxicity (U.S. FWS and University of Wyoming, 1987). In addition, reduced growth has been found in this assessment to satisfy the four acceptance criteria for biological responses [43 CFR § 11.62(f)(2)(i-iv)]. Specifically, reduced growth is:

- Often the result of exposure to hazardous substances, as shown in various scientific studies

- Caused in free-ranging organisms by exposure to hazardous substances

- Found in controlled laboratory experiments by exposure to hazardous substances

- A routine measurement that is practical to perform and produces scientifically valid results.

In addition, the following physiological health impairments were found in fish:

- Gut impaction and constipation

- Degeneration of the digestive system and cell loss

- Lipid peroxidation

- Histopathological deformation

Each of these health impairments likely causes reduced survival in the field, and hence contributes to overall population reductions in Silver Bow Creek and the Clark Fork River. The following section (Section 6.4 — Injury Determination) shows that the above injuries to fish have been caused by exposure to hazardous substances.

6.4 INJURY DETERMINATION: RESULTS OF TESTING AND SAMPLING

This section presents the determination, based on the results of field and laboratory testing and sampling, that fishery resources of the Silver Bow Creek and the Clark Fork River have been injured as a result of releases of the hazardous substances arsenic, cadmium, copper, lead, and zinc.

Included in this section are subsections that address fishkill investigations in the Clark Fork River, *in situ* bioassays conducted in the Clark Fork River and in Silver Bow Creek, laboratory toxicity tests of surface water exposures, laboratory toxicity tests of food-chain exposures, behavioral avoidance of hazardous substances, and laboratory and field analysis of reduced growth and physiological health impairment.

6.4.1 Category of Injury: Death/Fishkill Investigations

Fishkills have not been documented in Silver Bow Creek, because Silver Bow Creek does not support a fish population (Section 6.5; Johnson and Schmidt, 1988).

Fishkills in the Clark Fork River have occurred regularly. Phillips (1992) compiled a review of observed Clark Fork River fishkills between 1959 and 1991. Averett (1961) reported on fishkills in the Clark Fork River between 1958 and 1960. Between 1983 and 1991 there were at least eight documented fishkills in the upper Clark Fork River, some killing several thousand fish (Phillips, 1992) (Table 6-1). Most of the observed fishkills occurred in association with summer thunderstorm activity, when runoff across floodplain tailings deposits releases pulses of hazardous substances. As indicated in Table 6-1, fishkills have been observed from the Mill-Willow Bypass (at the Warm Springs Ponds) as far downstream as Rock Creek, and have resulted in mortality to trout and other fish species, including both juvenile and adult fish.

Most fishkills that have been observed in the Clark Fork River were investigated by the State Pollution Control Biologist or other trained State personnel, following the guidance of the Montana DFWP and Montana DHES (1988) fishkill investigation document (G. Phillips, Montana DFWP, *pers. comm.*).

Many of the reports listed in Table 6-1 provide water quality data and/or hazardous substance residue data from dead fish. These data all point to hazardous substances such as copper and zinc as the cause of fishkills. For example, the 1989 fishkill in Mill-Willow Bypass and the Clark Fork from Warm Springs Ponds to Deer Lodge (Phillips and Kerr, 1989) occurred when copper and zinc in the water were well above the acute Ambient Water Quality Criteria (AWQC) (see Chapter 4.0). In the Mill-Willow Bypass, concentrations of copper and zinc were both two *orders of magnitude* (i.e., at least one hundred times) above the acute AWQC. Copper concentrations were well above the

Table 6-1
Documented Fishkills in the Clark Fork River, 1959-1991
(Compiled by Phillips, 1992)

Date	Location; Details
December 1, 1959[1]	Near Rock Creek; at least 17 fish found, including whitefish, suckers, shiners, and squawfish
July 30, 1962[1]	Between Warm Springs and Racetrack; 39 dead fish counted, 650 total dead estimated
August 23, 1973[2]	Near Deer Lodge; several hundred adult fish (all species) and several thousand juvenile fish dead after thunderstorm
August 9, 1983[3]	Near Perkins Lane Bridge; associated with heavy thunderstorm
August 2, 1984[4]	Mill-Willow Bypass to Racetrack; over 10,000 fish (estimated) killed after heavy thunderstorm
June 18, 1987[2]	Near Lost Creek Bridge; approximately 50 brown trout dead after thunderstorm
July 3, 1987[5]	Near Mill-Willow Bypass & downstream of Warm Springs Ponds
May 27, 1988[2]	Near Mill-Willow Bypass; trout, suckers, whitefish killed after thunderstorm
July 12, 1989[6]	Mill-Willow Bypass to Deer Lodge; over 5,000 fish killed after thunderstorm
July 2, 1990[7]	Mill-Willow Bypass near Hog Hole; 100 juvenile brown trout, whitefish, and suckers kill after thunderstorm
August 20, 1991[2]	Below Racetrack Creek Bridge; over 200 fish killed (mostly brown trout) after intense thunderstorm

1 Averett, 1960.
2 Phillips, 1992.
3 Phillips, 1983.
4 Pedersen and Phillips, 1984.
5 Phillips, 1987.
6 Phillips and Kerr, 1989.
7 Spoon, 1990.

AWQC in the Clark Fork River at Warm Springs Bridge, Perkins Lane Bridge, and Galen, and were still above the AWQC a full day after the thunderstorm (Phillips and Kerr, 1989).

Hazardous substance residues in brown trout killed in the 1989 kill were extremely elevated. Fish killed in the Mill-Willow Bypass contained extremely elevated concentrations of cadmium, copper, and zinc in the gills; the mean gill concentrations of four fish tested were 5.6 ppm Cd, 683 ppm Cu, and 888 ppm Zn (dry weight). By comparison, brown trout collected from control streams contained mean gill concentrations of 0.3 ppm Cd and 9 ppm Cu (dry weight) (see Section 6.4.7).

Elevated concentrations of hazardous substances in both water and fish tissue have been documented for other fishkills as well (i.e., Pedersen and Phillips, 1984; Phillips, 1988; Phillips, 1992). The cause of these fishkills in the Mill-Willow Bypass and the upper Clark Fork River has been releases of hazardous substances from the floodplain to the river during intense thunderstorms. Section 6.4.3 describes laboratory toxicity studies that document the acute lethality of pulses of hazardous substances similar to those measured during fishkills.

6.4.2 Category of Injury: Death/*In Situ* Bioassays

The NRDA technical guidance document for assessing injury to fish (U.S. FWS and University of Wyoming, 1987) states that "the scientific literature is very convincing in demonstrating the utility of *in situ* (caged fish) bioassays for assessing the effects of...hazardous substances on fish mortality." In-stream bioassays have been conducted at various locations in the Clark Fork River. In 1960, Averett (1960) placed three live-boxes containing rainbow trout in the Clark Fork River ten miles upstream of Milltown Reservoir and three miles downstream of the Reservoir, as well as at a control site in Rattlesnake Creek. In less than three days, all trout in the Clark Fork River died, and a reddish-orange precipitate coating the gills was observed. All the trout in Rattlesnake Creek survived.

Recent *in situ* fish bioassays have been conducted in both the Clark Fork River and in Silver Bow Creek. During four years of testing (1986-1989), Phillips and Spoon (1990) found that mortality of rainbow trout fingerlings and fry in Silver Bow Creek and in many Clark Fork River sites was significantly higher than at control sites (Racetrack Creek and the Little Blackfoot River) (Table 6-2). The average copper and zinc concentrations over the testing period were one or two *orders of magnitude* higher in Silver Bow Creek than in controls; mortality was close to 90% in all tests and 100% in one of the tests (in one test, 68% of the trout died in the first day and the site was vandalized on the second day).

Table 6-2
Results of Four Years of *In Situ* Bioassays in the Clark Fork River and Silver Bow Creek and Control Sites, Using Fry and/or Fingerling Rainbow Trout

Location	Copper[1] (mean, μg/l)	Zinc[1] (mean, μg/l)	Hardness (mean, mg/l)	Cum. % Mortality	
				Fry	Fingerling
1986					
Racetrack Creek+	5	7	83	–	0
Silver Bow Creek	201	381	84	–	89*
CFR at Warm Springs	48	141	128	–	25*
CFR at Deer Lodge	59	67	177	–	15*
CFR at Gold Creek	55	60	145	–	7
CFR at Beavertail	55	83	155	–	21*
CFR at Clinton	28	44	103	–	3
1987					
Racetrack Creek+	6	12	110	8	2
Silver Bow Creek	219	478	116	92*	88*
CFR at Warm Springs	28	99	169	18	7
CFR at Gold Creek	14	35	172	36*	24*
CFR at Beavertail	15	31	192	55*	12*
CFR at Clinton	8	17	113	10	8

* Significantly higher mortality than in control sites ($\alpha = 0.05$).

Note: Mortality is the cumulative mortality. CFR = Clark Fork River.

1 Concentrations are Montana Total Recoverable
2 Mortality after one day; site was vandalized on the second day.
* Significantly higher mortality than control site ($\alpha = 0.05$).
\+ Control Location

Source: Phillips and Spoon, 1990.

Table 6-2 (cont.)
Results of Four Years of *In Situ* Bioassays in the Clark Fork River and Silver Bow Creek and Control Sites, Using Fry and/or Fingerling Rainbow Trout

Location	Copper[1] (mean, $\mu g/l$)	Zinc[1] (mean, $\mu g/l$)	Hardness (mean, mg/l)	Cum. % Mortality	
				Fry	Fingerling
1988					
Racetrack Creek[+]	1	8	95	0	–
Little Blackfoot River[+]	1	5	104	6	–
Silver Bow Creek	254	605	129	100[*]	–
Mill-Willow Bypass	39	52	153	22[*]	–
CFR at Warm Springs	30	57	154	7	–
CFR at Beck Hill	32	44	209	6	–
CFR at Gold Creek	24	34	175	5	–
CFR at Beavertail	25	42	199	16[*]	–
CFR at Clinton	17	36	107	0	–
1989					
Racetrack Creek[+]	1	6	95	2	–
Silver Bow Creek	–	–	–	68[*,2]	–
CFR at Beck Hill	27	44	196	25[*]	–
CFR at Gold Creek	18	28	157	33[*]	–
CFR at Beavertail	19	37	180	64[*]	–
CFR at Clinton	10	20	128	6	–

Note: Mortality is the cumulative mortality. CFR = Clark Fork River.

1 Concentrations are Montana Total Recoverable
2 Mortality after one day; site was vandalized on the second day.
* Significantly higher mortality than control site ($\alpha = 0.05$).
\+ Control Location

Source: Phillips and Spoon, 1990.

Clark Fork River mortality exceeded that at control sites at various locations over different years. For example, mortality was significantly higher at Beavertail than at the control location for both fry and fingerlings all four years. Significant mortality occurred in at least one of the four years in the Mill-Willow Bypass and the Clark Fork River at Warm Springs, Deer Lodge, Beck Hill, and Gold Creek. Only at Clinton, below Rock Creek, was mortality not significant in any year (Table 6-2). Of these locations in the Clark Fork River, Clinton is farthest downriver and the only one that supports a population of rainbow trout (see Section 6.5).

The significant rainbow trout mortality observed in Silver Bow Creek and the Clark Fork River confirm that ambient conditions cause trout mortality. The following sections provide laboratory confirmation that the hazardous substances found in the Clark Fork River are toxic to both rainbow and brown trout.

6.4.3 Category of Injury: Death/Exposure to Pulsed Hazardous Substances

Laboratory acute toxicity tests have been used extensively to show the toxicity of hazardous substances to fish (Rand and Petrocelli, 1985). The NRDA technical guidance document for determining fish injury (U.S. FWS and University of Wyoming, 1987) states that "...laboratory toxicity tests... for the detection of fish death response are the most thoroughly validated of all fish injury responses considered." A number of distinct laboratory toxicity tests were performed to determine the effects of hazardous substances on fish; this section examines the effects of pulsed concentrations of hazardous substances on trout.

In order to test whether "pulses" containing elevated concentrations of the hazardous substances copper, cadmium, zinc, and lead were lethal to trout, a laboratory study was conducted in which brown and rainbow trout were exposed to concentrations of hazardous substances representative of conditions observed in the Clark Fork River during fishkills (Appendix B[1] describes, in detail, the objectives, methods, results, and conclusions of this laboratory study).

Hatchery stocks of brown and rainbow trout, as well as a wild stock of brown trout raised from eggs collected and fertilized from free-ranging fish collected from the Clark Fork River (near Warm Springs) were used to test the acute toxicity of hazardous substance pulses. Acute pulse tests were conducted in which concentrations of hazardous substances were gradually increased, held constant, and then decreased over an eight-hour period. Six separate tests were conducted in which trout fry were exposed to pulses of metals. Each test was conducted using hatchery brown and rainbow trout. Clark Fork

[1] "Research Report on Injury Determination, Fishery Protocol #3," by H.L. Bergman.

River brown trout were exposed in two of the six tests. Five different combinations of hardness and pH were used (one combination was used twice). In each test, trout were exposed to a ratio of hazardous substances similar to concentrations measured in the Clark Fork during storms and "redwater" events (Table 6-3). The base pulse concentrations, defined as the "1P" metals concentration, were 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. The trout in each test were exposed to 1P, 2P, 4P, and 8P metals concentrations, with control trout being exposed to 0P (no metals). Thus, the highest nominal concentrations of metals to which the fish were exposed (8P) was 1,840 ppb zinc, 960 ppb copper, 25.6 ppb lead, and 16.0 ppb cadmium.

In each of the six tests, the water was brought to full pulse conditions (i.e., nominal levels of metals, hardness, and pH reached) over a one hour period. The fish then were exposed to the full pulse conditions for a total of six hours. The water was then returned to initial conditions over another one hour period. Thus, these pulses were "1-6-1" pulses, where the first "1" represents the time (hours) to reach pulse conditions, the "6" represents the duration (hours) of the pulse conditions, and the second "1" represents the time (hours) to return to initial conditions. After the pulses, the trout were monitored for 96 hours, with mortality recorded twice daily.

Similar tests were conducted to compare the relative sensitivity of hatchery brown and rainbow trout fry and juveniles (juveniles are larger than fry[2]) to hazardous substance pulses. These tests differed from the six fry-only tests in that 1) Clark Fork brown trout juveniles were unavailable and hence were not tested, 2) juveniles were tested using a 2-4-2 pulse, and 3) only one combination of hardness and pH was employed (initial hardness = 200 ppm, pulse hardness 100 ppm; initial pH = 7.2 - 8.0, pulse pH = 4.5).

As described in Appendix B, survival of both brown and rainbow trout was significantly reduced when trout were exposed to concentrations of Cd, Cu, Pb, and Zn at concentrations measured in the Clark Fork River (Table 6-4; Figures 6-2a to 6-2f). Concentrations of metals as low as 1P caused significant mortality in rainbow trout, concentrations as low as 2P caused significant mortality in hatchery brown trout, and concentrations as low as 4P caused significant mortality in Clark Fork River brown trout.[3] This study demonstrated that:

- Pulse-induced mortality was exacerbated when pH and hardness decreased during the pulse. Such conditions have been observed in the Clark Fork River during pulse events.

[2] Juveniles had a mean weight of 21.2 g and a mean length of 126.5 mm. Fry had a mean weight of 0.18 g and a mean length of 28.6 mm (Appendix B).

[3] Clark Fork River brown trout were only used in two of the six tests; their sensitivity to pulses in these two tests was similar to that of the hatchery brown trout.

Table 6-3
Metal Concentrations Measured in the Upper Clark Fork River (CFR), Montana During Storm "Pulse" Events and "Redwater" Spill Events
(concentrations in $\mu g/l$ (ppb) total recoverable unless otherwise noted)

Date	Sample Collection Location	Event	Metal Concentration ($\mu g/L$)			
			Zn	Cu	Pb	Cd
March 10, 1960[a]	CFR below Warm Springs Ponds	redwater	--	9,000	--	--
	CFR above East Missoula	redwater	--	3,100	--	--
May 1, 1968	CFR between Garrison and Deer Lodge	redwater	4.3	620	--	--
November 20, 1968	CFR Near Warm Springs	redwater	32,500	4,000	--	--
April 10, 1969	CFR at Deer Lodge	redwater	3,600	1,100	--	--
March 1, 1972	CFR near Warm Springs	redwater	500	820	--	--
May 27, 1988[b]	Mill-Willow Bypass	storm event	3,250	2,480	--	--
July 12, 1989[b]	Mill-Willow Bypass	storm event	14,000	13,300	30	85
	CFR below Warm Springs		800	450	10	6
	CFR at Perkins Lane		120	180	4	3
	CFR near Galen		210	370	2	3
	CFR at Deer Lodge (total recoverable)		560	330	15	3
	(dissolved)		230	120	<1	2
July 2, 1990[b]	Mill-Willow Bypass	storm event	10,300	5,800	--	--

[a] Water samples collected in association with mortality to caged fish placed instream; no dead native fish observed.
[b] Water samples collected and analyzed in association with a documented fishkill.

Source: Appendix B

Table 6-4
Concentrations of Hazardous Substances that Caused Significant Mortality During an Eight-Hour Pulse Exposure

	Hardness (ppm as $CaCO_3$)		pH		Hatchery Brown Trout	Hatchery Rainbow Trout	Clark Fork Brown Trout
	Initial	Pulse	Initial	Pulse			
Test I	100	100	7.2 - 8.0	7.2 - 8.0	4P, 8P (73, 100)	4P, 8P (37, 100)	
Test II	100	50	7.2 - 8.0	7.2 - 8.0	2P, 4P, 8P (82, 100, 100)	1P, 2P, 4P, 8P (9, 100, 100, 100)	
Test III	100	50	7.2 - 8.0	4.5	4P, 8P (90, 100)	1P, 2P, 4P, 8P (27, 90, 100, 100)	
Test IV	200	100	7.2 - 8.0	4.5	4P, 8P (30, 100)	1P, 2P, 4P, 8P (8, 68, 100, 100)	4P, 8P (27, 100)
Test V	200	100	7.2 - 8.0	4.5	4P, 8P (73, 100)	2P, 4P, 8P (33, 100, 100)	8P (92)
Test VI	200	400	7.2 - 8.0	4.5	no significant mortality	8P (38)	

Note: "1P" hazardous substance concentrations were as follows: 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Hardness and pH were varied for each test; "initial" refers to the respective levels before and after the pulse event, and "pulse" refers to the respective levels during the pulse event. *n*P refers to the proportional levels of the above hazardous substances where significant mortality (α = 0.05) occurred. Numbers in parentheses refer to the percent mortality of the trout in each respective test at the end of the 96-hr observation period.

Source: Appendix B.

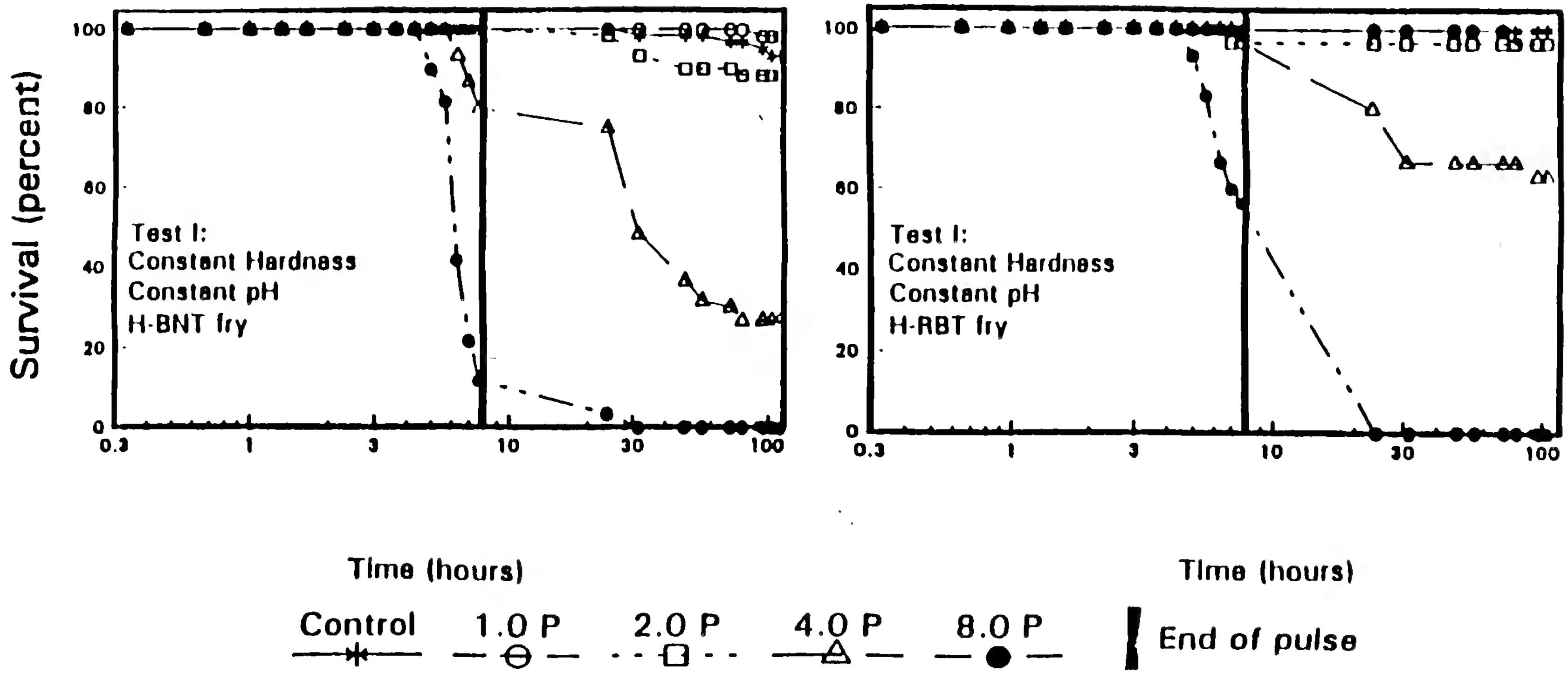

Figure 6-2a. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Test conditions shown in Table 6-4. Source: Appendix B.

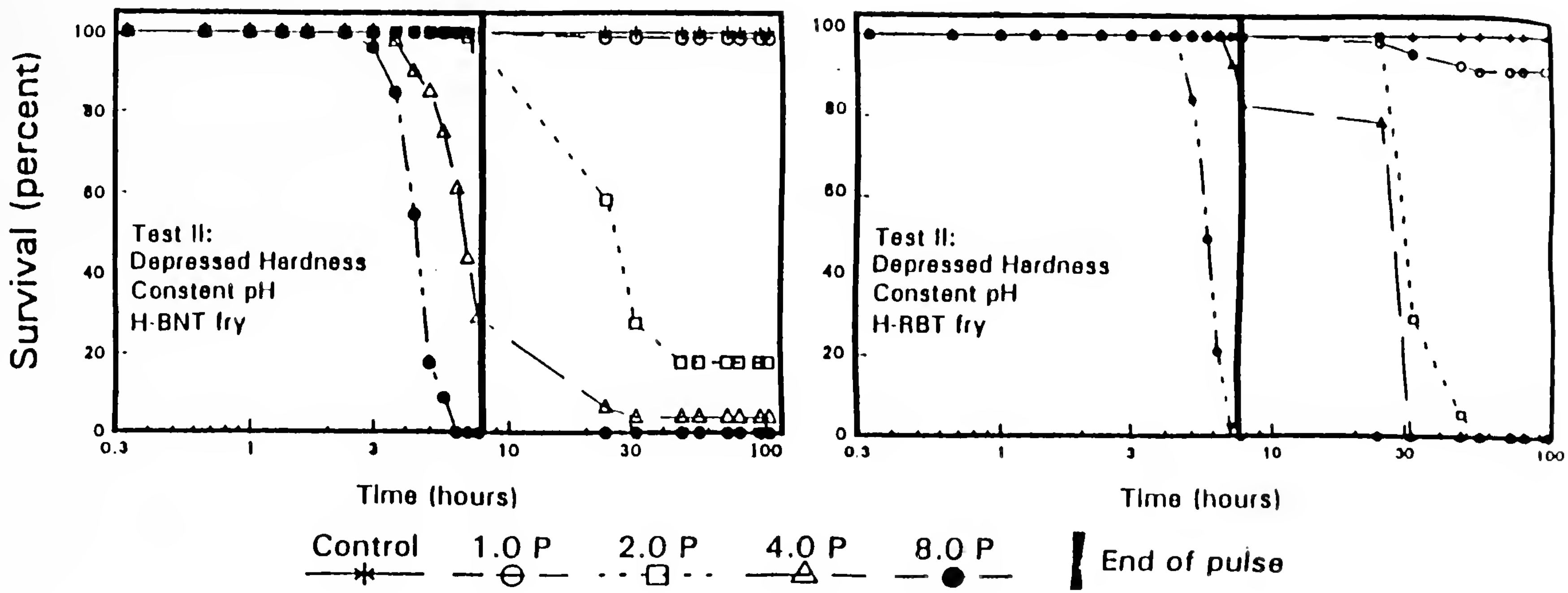

Figure 6-2b. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Test conditions shown in Table 6-4. Source: Appendix B.

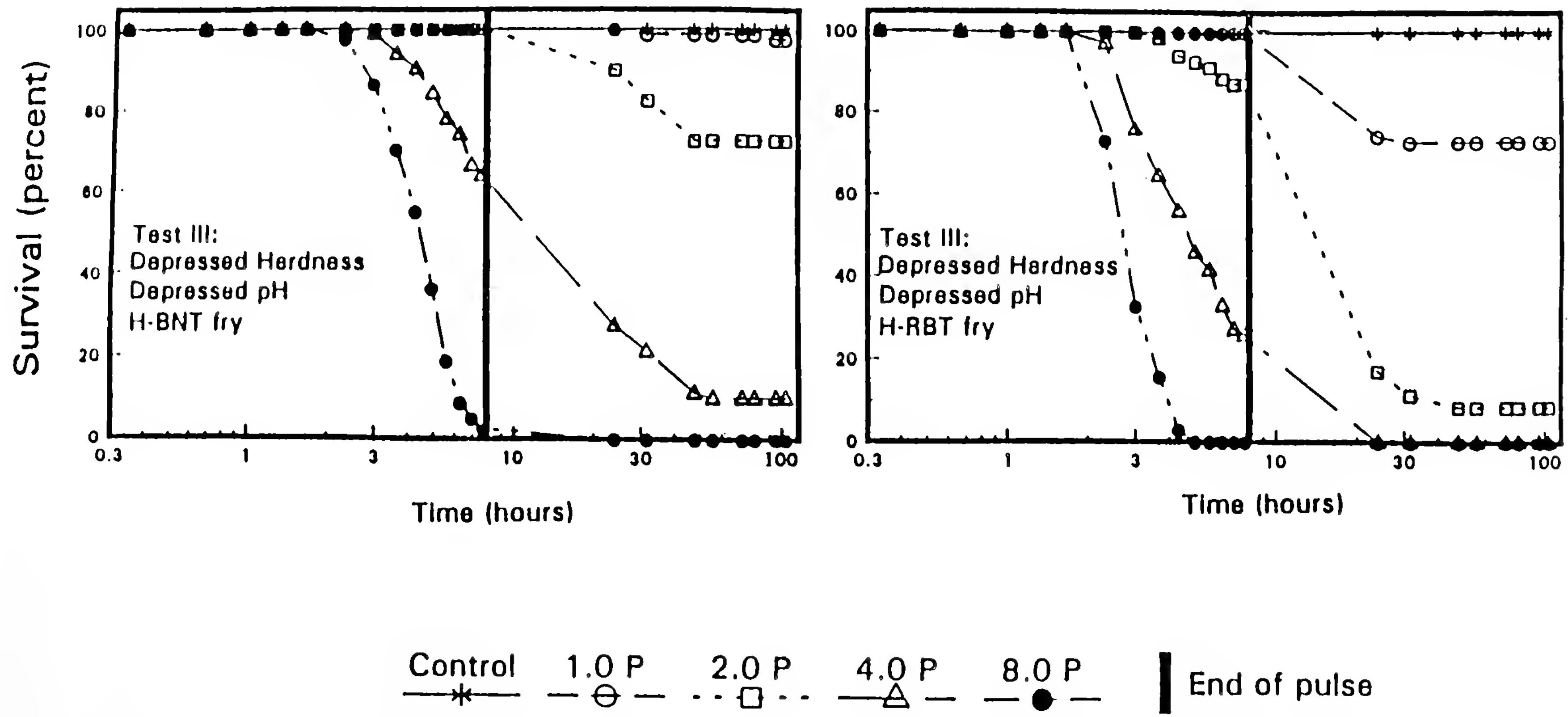

Figure 6-2c. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Source: Appendix B.

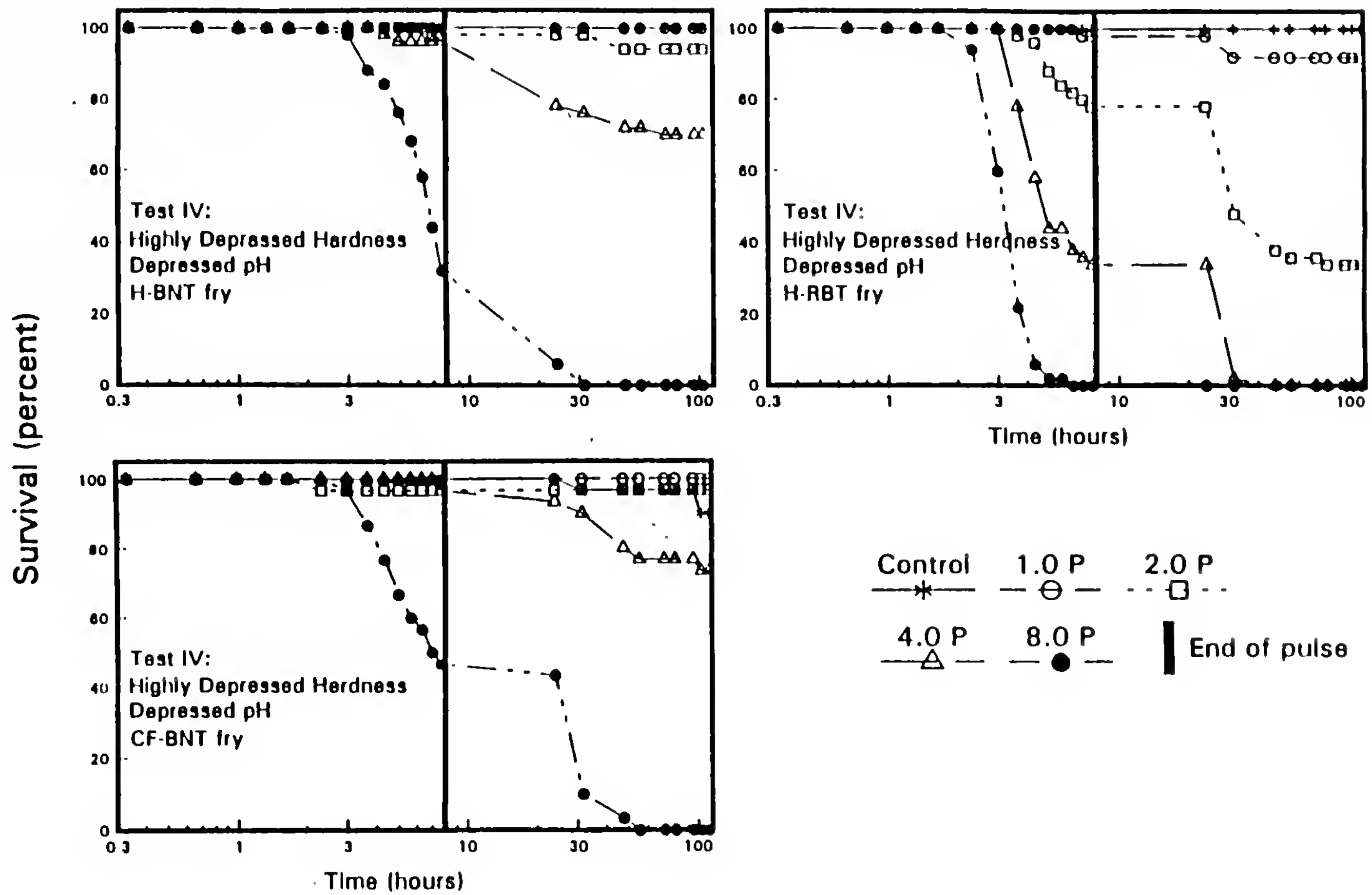

Figure 6-2d. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) and Clark Fork Brown Trout (CF-BNT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Source: Appendix B.

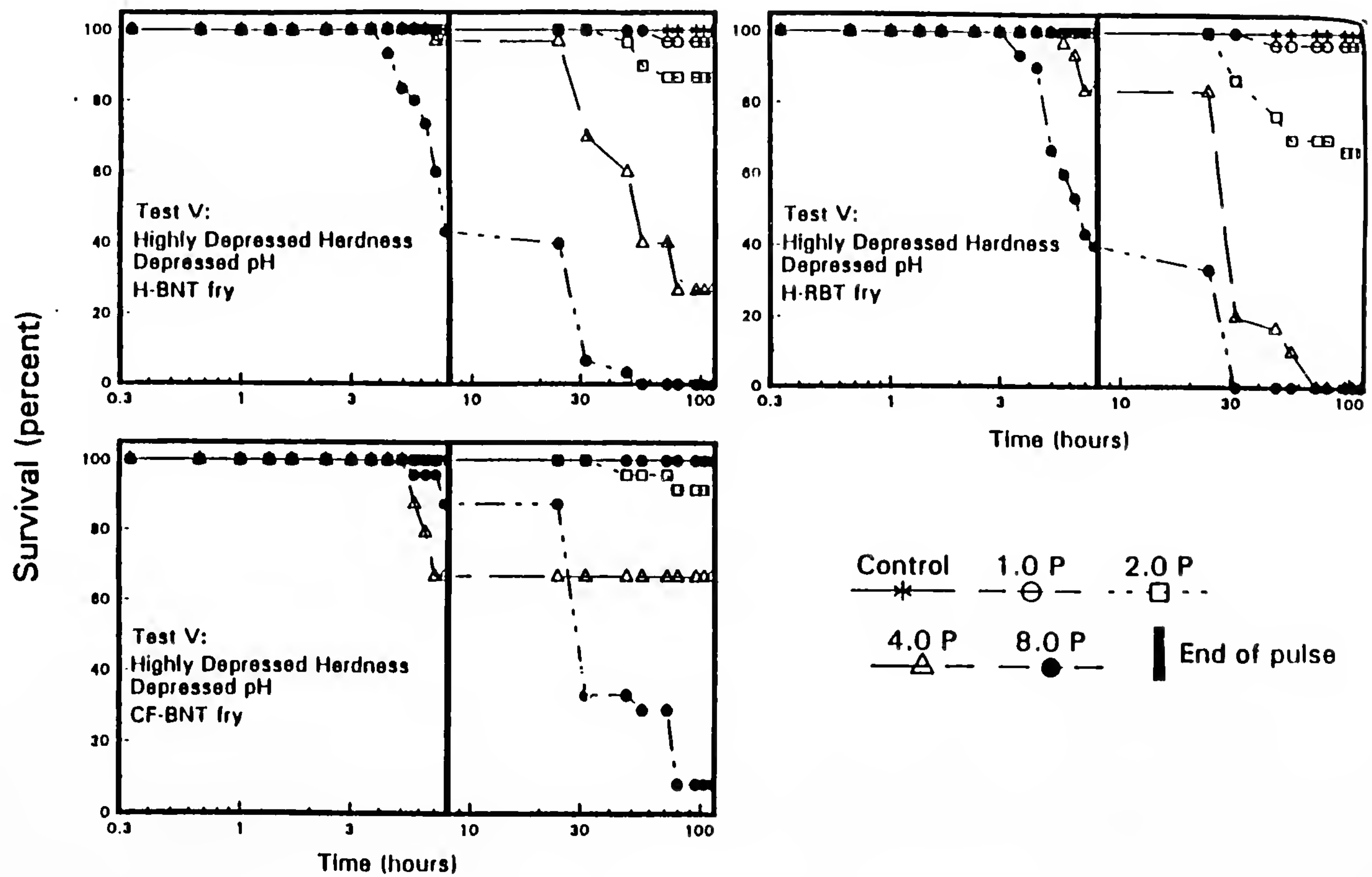

Figure 6-2e. **Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) and Clark Fork Brown Trout (CF-BNT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event.** "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Source: Appendix B.

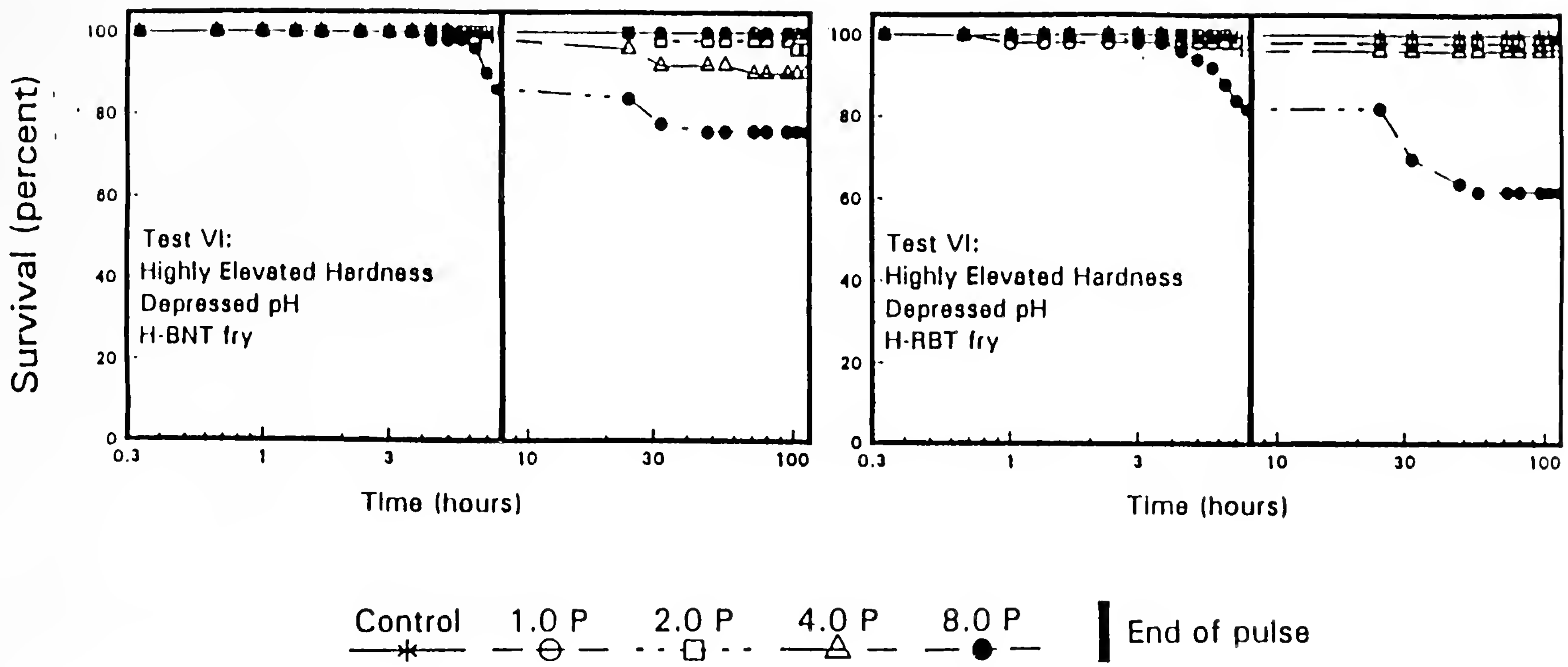

Figure 6-2f. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Source: Appendix B.

- Rainbow trout fry were more sensitive (i.e., higher mortality) than brown fry trout to pulses in which pH and hardness were reduced. This may explain, in part, the absence of rainbow trout in the upper portion of the Clark Fork River.

- Mortality was observed as early as three hours after the start of the pulse.

These results show that significant mortality (relative to the control exposure) was observed in both brown and rainbow trout fry when exposed to the pulses of hazardous substances. Concentrations of hazardous substances as low as the "1P" dilution for rainbow trout (again, "P" = 230 ppb Zn, 120 ppb Cu, 3.2 ppb Pb, and 2.0 ppb Cd), 2P for hatchery brown trout, and 4P for Clark Fork River trout, caused significant mortality. Acute mortality was exacerbated when either hardness or pH decreased during the exposure. In addition, in almost all tests, rainbow trout were more sensitive to metals pulses than either hatchery brown trout or Clark Fork River brown trout.[4] As described in Appendix B, the results of this study are consistent with the scientific literature.

Additional tests were performed in order to assess the relative sensitivity of fry and juvenile trout. As shown in Table 6-5 and Figures 6-3a and 6-3b, rainbow trout fry and juveniles had similar sensitivity to metal pulses. Brown trout juveniles, however, were more resistant to the metals pulses than were brown trout fry. This result suggests that pulse-induced fishkills would be expected to affect small fish to a greater extent than larger fish. Such fishkills may go unnoticed, however, because small fish are less likely to be observed.

Conclusions

Overall, the data from this study support the following conclusions:

- "Pulses" of hazardous substances simulating conditions in the Clark Fork River during fishkills were acutely lethal to both brown and rainbow trout in laboratory exposures.

- Significant mortality was found in both fry and juvenile rainbow and brown trout.

- When hardness was decreased during the pulse exposures (as has been reported in the Clark Fork River), mortality was significantly greater than when hardness was held constant.

[4] Brown trout were more sensitive when hardness and pH were held constant.

Table 6-5
Concentrations of Hazardous Substances that Caused Significant Mortality During an Eight-Hour Pulse Exposure

Hardness (ppm as $CaCO_3$)		pH		Brown Trout Fry	Brown Trout Juveniles	Rainbow Trout Fry	Rainbow Trout Juveniles
Initial	Pulse	Initial	Pulse				
200	100	7.2 - 8.0	4.5	4P, 8P (45, 85)	8P (40)	4P, 8P (80, 100)	4P, 8P (95, 100)

Note: "1P" hazardous substance concentrations were as follows: 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Hardness and pH were varied for each test; "initial" refers to the respective levels before and after the pulse event, and "pulse" refers to the respective levels during the pulse event. *n*P refers to the proportional levels of the above hazardous substances where significant mortality ($\alpha = 0.05$) occurred. Numbers in parentheses refer to the percent mortality of the trout in each respective test at the end of the 96-hour observation period.

Source: Appendix B.

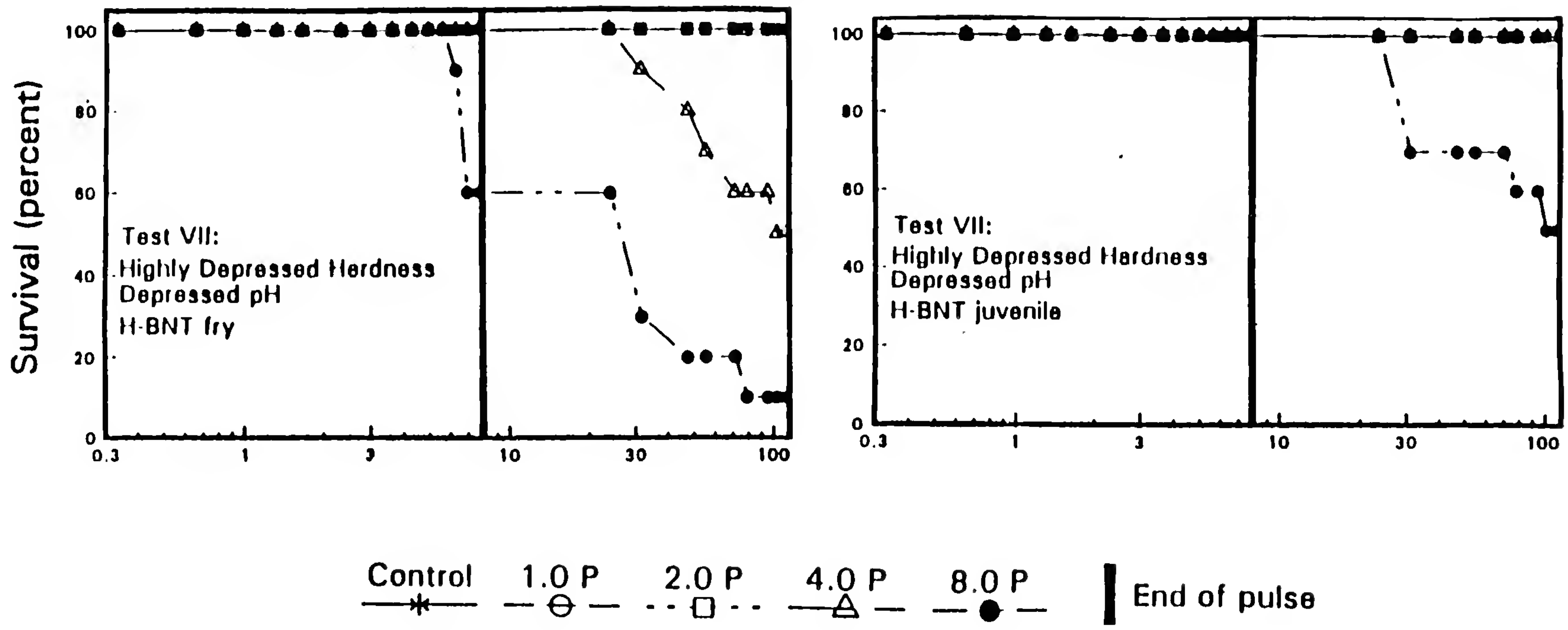

Figure 6-3a. **Cumulative Survival of Hatchery-Reared Brown Trout (H-BNT) Fry and Juveniles During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event (First Replicate).** "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium.

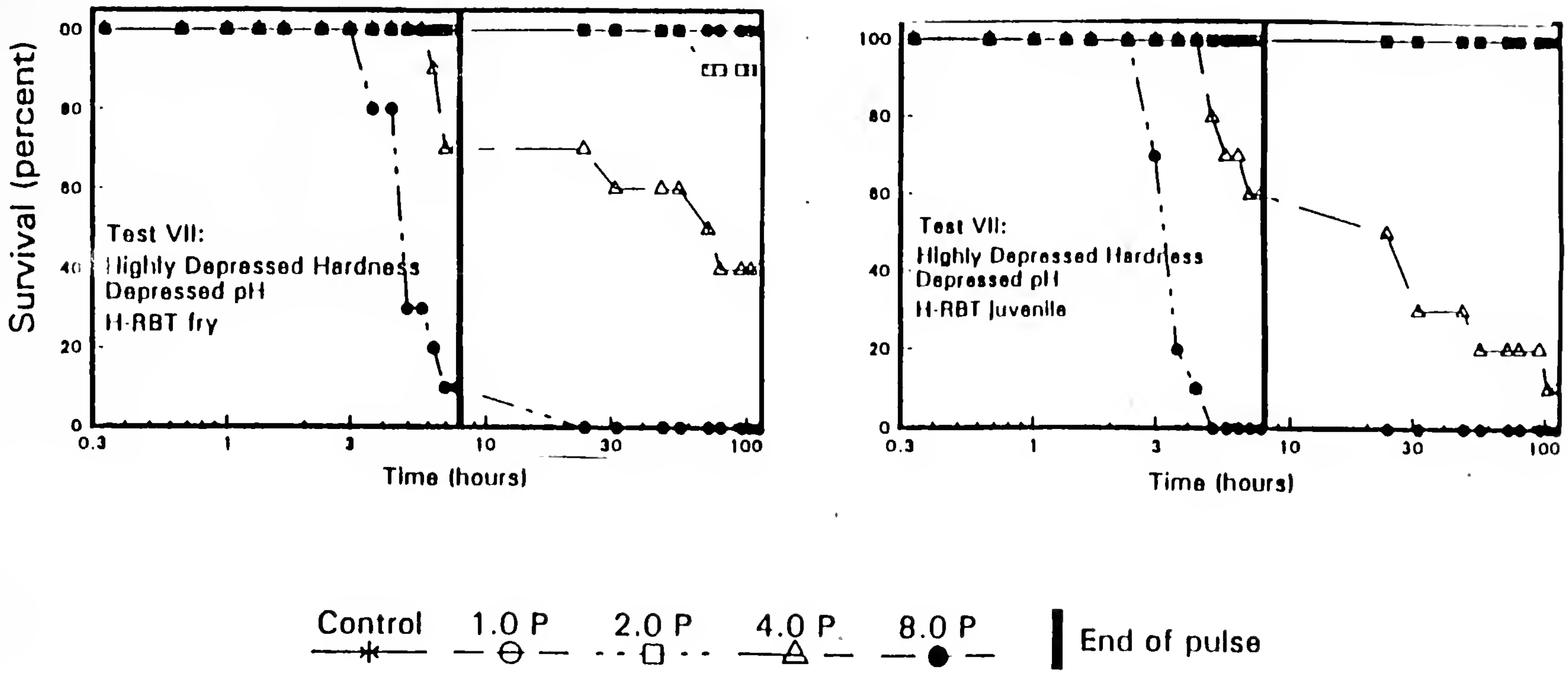

Figure 6-3b. **Cumulative Survival of Hatchery-Reared Rainbow Trout Fry (H-RBT) and Juveniles During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event (First Replicate).** "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium.

- Rainbow trout were more sensitive to pulse exposures than brown trout when hardness was decreased.

- When pH was decreased during the pulse exposures (as has been documented in the Clark Fork River), mortality was greater in rainbow trout, and less in hatchery brown trout than when pH was held constant.

- Clark Fork River brown trout had similar sensitivity to pulse exposures as did hatchery brown trout in one test, and were more tolerant than hatchery brown trout in a second replicate test.

- In general, the order of species/size sensitivity to pulses was rainbow trout fry ≈ rainbow trout juveniles > brown trout fry > brown trout juveniles.

In most cases, the rainbow trout fry were more sensitive to the pulses than were the brown trout fry. This result is consistent with the absence of rainbow trout in the upper reaches of the Clark Fork River. In addition, the pulse tests demonstrated that brown trout fry are more sensitive to pulses than are brown trout juveniles.

Because the high runoff pulse events usually are associated with turbid water, and because trout fry are very small (and hence are not readily observed), fishkills involving trout fry are likely to have occurred far more often than the documented kills of much larger fish.

The results of the pulse tests demonstrated that reductions in hardness and pH resulted in an increase in the toxicity of metals to trout. During many of the high runoff events recorded in the Clark Fork River, hazardous substance concentrations increase while hardness and pH decrease. For example, Table 6-6 presents water quality conditions measured during the May 27, 1988 fishkill. <u>Measured</u> copper and zinc concentrations near the beginning of the pulse were as high as 2,480 $\mu g/l$ and 3,250 $\mu g/l$, respectively (20 and 14 times the "P" concentrations). Both pH and hardness also decreased during this pulse. Moreover, as shown by the concentrations of copper and zinc in tailings runoff during two storm events (over 1,000 times the "P" concentrations), these <u>measured</u> instream concentrations (with downstream dilution) likely do not represent the maximum pulse concentrations that would occur directly downstream of tailings runoff. Overall, the results of the pulse experiments clearly support the conclusion that pulses of hazardous substances are responsible for acute trout mortality in the Clark Fork River.

Table 6-6
Hazardous Substance Concentrations in Mill-Willow Bypass and the Clark Fork River During May 27, 1988 Fishkill

Location	Time	pH	Alkalinity (as $CaCO_3$)	Hardness (as $CaCO_3$)	Copper (µg/l)	Zinc (µg/l)	Copper (xP)	Zinc (xP)
Mill-Willow Bypass near Hog Hole[1]	3:50 pm	4.79	1.2	160	2,480	3,250	20.7	14.1
Mill-Willow Bypass near Pond 2[1]	4:00 pm	5.52	7.8	164	1,800	2,460	15.0	10.7
Clark Fork River below Warm Springs Creek bridge[1]	4:30 pm	7.24	61.0	133	70	120	0.6	0.5
Mill-Willow Bypass near Pond 2[1]	5:15 pm	7.18	38.0	112	280	320	2.3	1.4
Mill-Willow Bypass near Pond 2[1]	6:10 pm	7.25	45.0	109	100	90	0.8	0.4
Tailings runoff[2]	NA	NA	NA	NA	640,000	NA	5,333	NA
Tailings runoff[3]	NA	NA	NA	NA	217,500	273,000	1,813	1,187

1 MDHES and CH_2M Hill, 1989.
2 Concentration measured in simulated storm event runoff from tailings several miles above the Mill-Willow Bypass (MDHES and CH_2M Hill, 1989).
3 Concentrations are averages of those measured in runoff during two storm events: Colorado Tailings (July 8, 1986) and Ramsay Flats (July 16, 1986).

6.4.4 Category of Injury: Death/Exposure to Acute Concentrations of Hazardous Substances

In a separate study (Appendix C[5]), hatchery-reared brown and rainbow trout, as well as Clark Fork River brown trout, were exposed to various concentrations of hazardous substances (cadmium, copper, lead, and zinc), representative of conditions that are found in the Clark Fork River. The objectives of this study were to assess whether:

1. Exposure to metals concentrations observed in Clark Fork River causes mortality in brown and rainbow trout.

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5 "Research Report on Injury Determination, Fishery Protocol #5," by H.L. Bergman.

2. Clark Fork River brown trout are genetically adapted to tolerate elevated concentrations of metals.

6.4.4.1 Determination of Median Lethal Concentrations (LC50s)

As described in Appendix C, hatchery-reared brown and rainbow trout, as well as brown trout from the Warm Springs area of the Clark Fork River, were exposed to water containing zinc, copper, lead, and cadmium to assess mortality. Trout were exposed to concentrations of 5P, 2.5P, 1.2P, 0.6P, and 0.3P, where 1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Thus, the fish were exposed to nominal metals concentrations ranging from 69 ppb zinc, 36 ppb copper, 1.0 ppb lead, and 0.6 ppb cadmium (0.3P dilution), to 1,150 ppb zinc, 600 ppb copper, 16 ppb lead, and 10 ppb cadmium (5P dilution). Mortality was monitored during each test (Figure 6-4) and LC50s, the concentrations which caused mortality in 50% of the test organisms, were calculated (Table 6-7 and Figure 6-5).

At both the 48- and 96-hour interval, rainbow trout had significantly higher LC50s (i.e., were less sensitive) than did either Clark Fork or hatchery brown trout. At 48 hours, the LC50s for the two brown trout categories were not significantly different. However, after 96 hours, Clark Fork brown trout had a significantly lower LC50 (i.e., were more sensitive) than the hatchery brown trout. Thus, at 96 hours, rainbow trout were the least sensitive to hazardous substances (0.79P), whereas Clark Fork brown trout were the most sensitive to hazardous substances (0.42P).

The 96-hour LC50 for Clark Fork brown trout, 0.42P, was equivalent to 97 ppb zinc, 78 ppb copper, 0.02 ppb lead, and 1.3 ppb cadmium.[6] Concentrations of those hazardous substances at that magnitude have been documented regularly in Silver Bow Creek and the Clark Fork River (see Chapter 4.0 - Surface Water). Even the highest 96-hour LC50, 0.79P (Table 6-7), falls within the range of metals concentrations documented in Silver Bow Creek and the Clark Fork River.

Moreover, it should be emphasized that the measurement endpoint used in this study, the LC50, does *not* represent an injury *threshold*. Metals concentrations could cause substantial fishkills at "LC10" or "LC1" concentrations (i.e., 10% or 1%, respectively, of an exposed fish population would be killed). Such concentrations would be *lower* than the LC50 concentrations.

[6] LC50s based on measured concentrations (Appendix C).

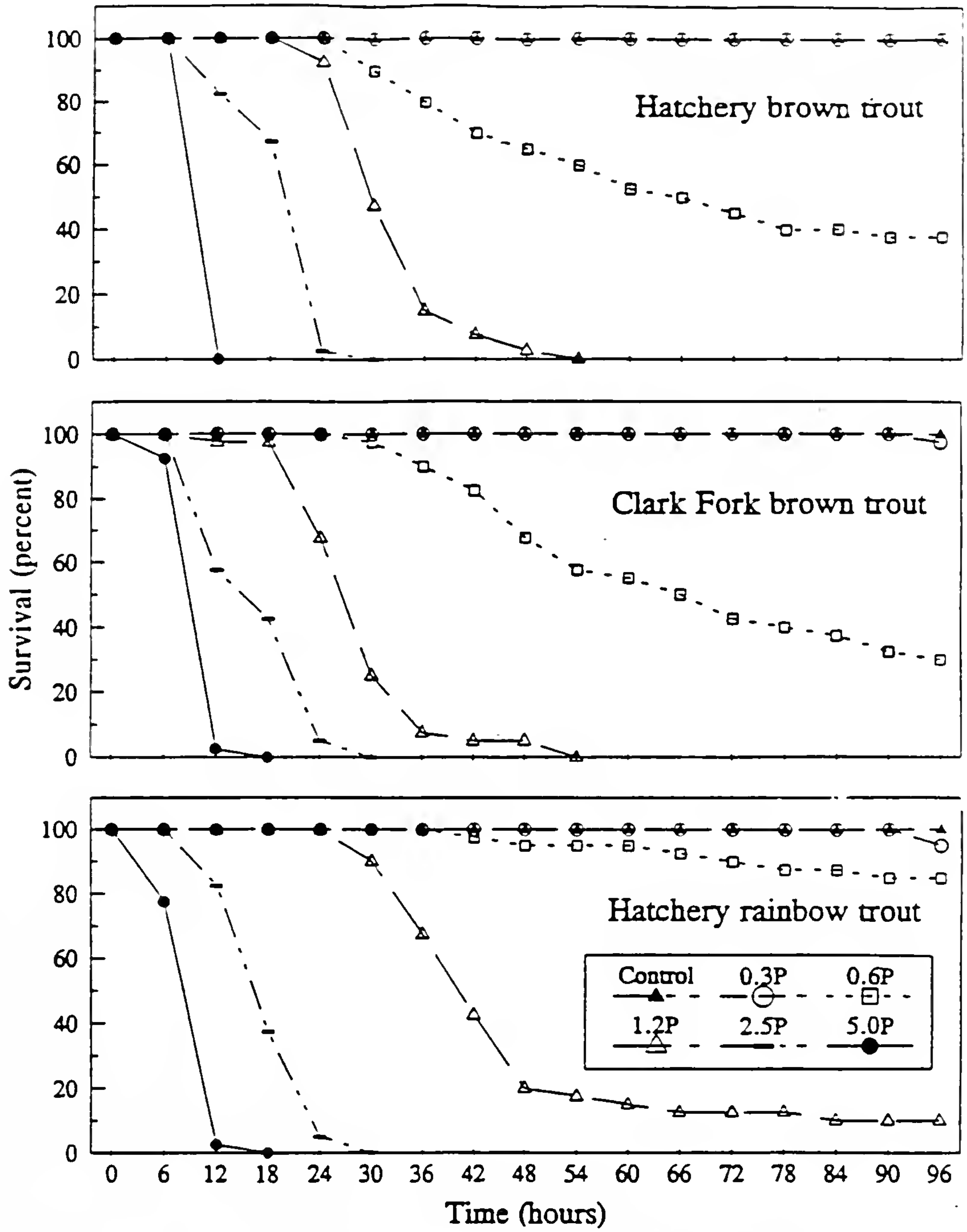

Figure 6-4. **Cumulative Percent Survival for Hatchery Brown Trout, Clark Fork Brown Trout, and Rainbow Trout Exposed to "p" Dilutions of Zn, Cu, Pb, and Cd, where 1P = 230 ppb Zn, 120 ppb Cu, 3.2 ppb Pb, and 2.0 ppb Cd.** Source: Appendix C.

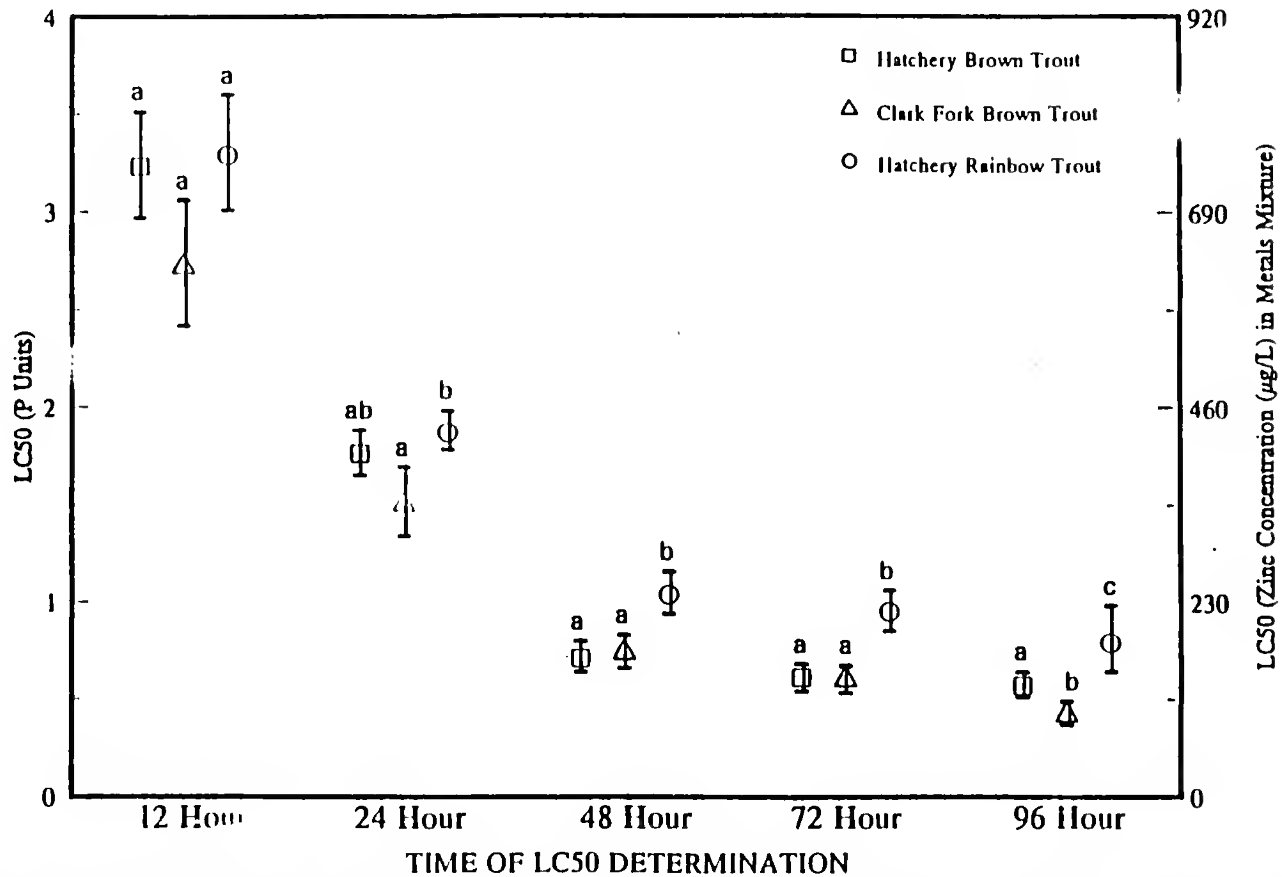

Figure 6-5. **Median Lethal Concentrations (LC50s) and 95% Confidence Intervals at 12- to 96-Hour Intervals for Hatchery Brown and Rainbow Trout and Clark Fork River Brown Trout Exposed to Dilutions of a Mixture of Zinc, Copper, Lead, and Cadmium.** LC50s are in "P Units", or multiples of the 1P concentration, where 1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. LC50 values with the same subscripted letter are not significantly different ($\alpha = 0.05$); those with different letters are significantly different. Source: Appendix C.

Table 6-7
48- and 96-Hour LC50s for Three Trout Species/Stocks

Species/Stock	48-h LC50	96-h LC50
Hatchery brown trout	0.71P	0.57P**
Clark Fork brown trout	0.74P	0.42P
Hatchery rainbow trout	1.04P*	0.79P*

Note: LC50s are in multiples of "P", where 1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium.

* Value is significantly higher than both brown trout LC50s ($\alpha = 0.05$).
** Value is significantly higher than the Clark Fork brown trout 96-h LC50 and significantly lower than the rainbow trout 96-h LC50 ($\alpha = 0.05$).

Source: Appendix C.

Overall, the results of these tests demonstrate that exposure to concentrations of hazardous substances at concentrations observed in the Clark Fork River causes trout mortality.

6.4.4.2 Determination of Time to Death

The relative sensitivity to hazardous substances between species/stocks can be ascertained by determining the length of time that organisms can survive in the presence of hazardous substances. Resistance is normally measured as the "median time to death," or LT50 (Sprague, 1985). This test is useful for determining whether a given species or organism can acclimate to lethal conditions; the longer the organisms survive under the given conditions, the greater the level of acclimation.

In order to assess the ability of rainbow and brown trout (including hatchery and Clark Fork River stocks) to acclimate to — and hence resist — metals concentrations, LT50s were determined following varying periods of acclimation to low levels of hazardous substances (Appendix C). Three separate acclimation tests ("challenges") were performed. First, trout were acclimated for three weeks to nominal concentrations of zinc, copper, lead, and cadmium similar to ambient Clark Fork River conditions. The acclimation metals levels were 0.2P, where 1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Thus, the 0.2P level of metals was 46 ppb zinc, 24 ppb

copper, 0.6 ppb lead, and 0.4 ppb cadmium. The second acclimation test involved acclimating trout to the 0.2P metals for five weeks. The third test involved acclimating hatchery brown and rainbow trout to the 0.2P metals for six weeks, then returning the fish to control water (0P) for two weeks before beginning the test (Figure 6-6).

In all three tests, the acclimated fish were cold-branded for identification, placed in a test chamber with unacclimated fish (i.e., acclimated only to 0P control water), and exposed to 1P metals concentrations. Mortality was monitored every two hours for the first 12 hours, and every six hours for the remainder of the test. Both LT50s and the mean time to death were calculated.

The results of the three LT50 acclimation tests are summarized in Table 6-8 and Figures 6-7 through 6-9. Survival time (i.e., resistance to metals) increased significantly when fish (all species/stocks) were acclimated to low concentrations of metals. Although the results of the three week acclimation test (challenge I) appear to show that Clark Fork brown trout had a greater ability to acclimate to the hazardous substances than either of the hatchery trout species, this result likely occurred because the Clark Fork River trout tested were larger than the corresponding hatchery stock (see Appendix C). After five weeks of acclimation (challenge II), both brown trout stocks evidenced significantly greater resistance to the metals mixture than the rainbow trout; again, the apparent difference between the two brown trout stocks is likely an artifact of the size of the fish tested rather than genetic adaptation (Appendix C).

After six weeks of acclimation followed by two weeks de-acclimation in 0P water (challenge III), brown trout that were acclimated and then de-acclimated had a significantly *shorter* LT50 than did the control brown trout. (This test was only performed on hatchery trout due to a shortage of Clark Fork River brown trout.) The de-acclimated rainbow trout, on the other hand, had a significantly *longer* LT50 than the rainbow trout control, as well as a significantly longer LT50 than either the brown trout test or control. This *increased sensitivity* in the de-acclimated fish may reflect the physiological "cost of acclimation." The cost of acclimation has been associated in other studies with reduced growth (see Appendix C). The results of the de-acclimated challenge may indicate, however, that fish that have borne the physiological cost of acclimation may be less able to tolerate subsequent metals exposures following a de-acclimation period.

Summary and Conclusions

The results of the LC50 and LT50 studies support the following conclusions:

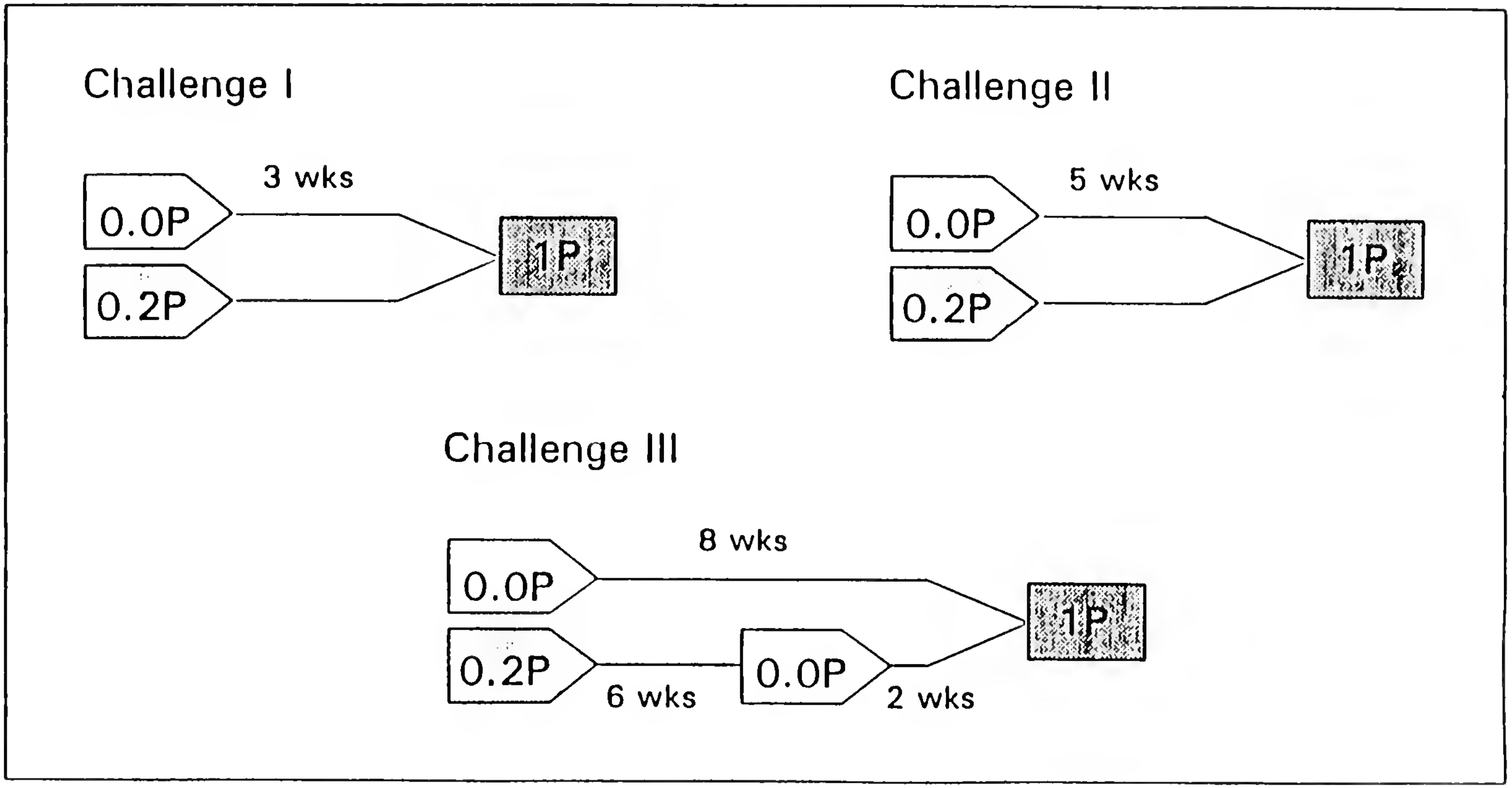

Figure 6-6. **Schematic Diagram of Three Experimental Challenges to Determine Time-to-Death.** "1P" concentration equal to 230 ppb Zn, 120 ppb Cu, 3.2 ppb Pb, and 2.0 ppb Cd. Source: Appendix C.

Table 6-8
LT50 Estimates (hours) for Hatchery Brown and Rainbow Trout and Clark Fork Brown Trout

Test Trout	LT50 (hours) (0P control)	LT50 (hours) (0.2P acclimated)
3 Weeks Acclimation		
Hatchery brown trout	24.5	39.9
Clark Fork brown trout	26.4	61.4
Hatchery rainbow trout	25.1	36.8
5 Weeks Acclimation		
Hatchery brown trout	29.1	95.7
Clark Fork brown trout	49.5	146.2
Hatchery rainbow trout	29.4	35.8
6 Weeks Acclimation + 2 Weeks De-acclimation		0.2P → 0P
Hatchery brown trout	31.3	19.9
Hatchery rainbow trout	25.8	42.7

Note: The control trout had no metals in acclimation water; test trout were acclimated to a 0.2P metals concentration (46 ppb zinc, 24 ppb copper, 0.6 ppb lead, and 0.4 ppb cadmium) for a designated period of time. After the acclimation period, test and control fish were exposed to 1P metals concentrations (1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium) until mortality was complete (unless otherwise indicated). Median time to death (LT50) was determined as described in Appendix C.

Source: Appendix C.

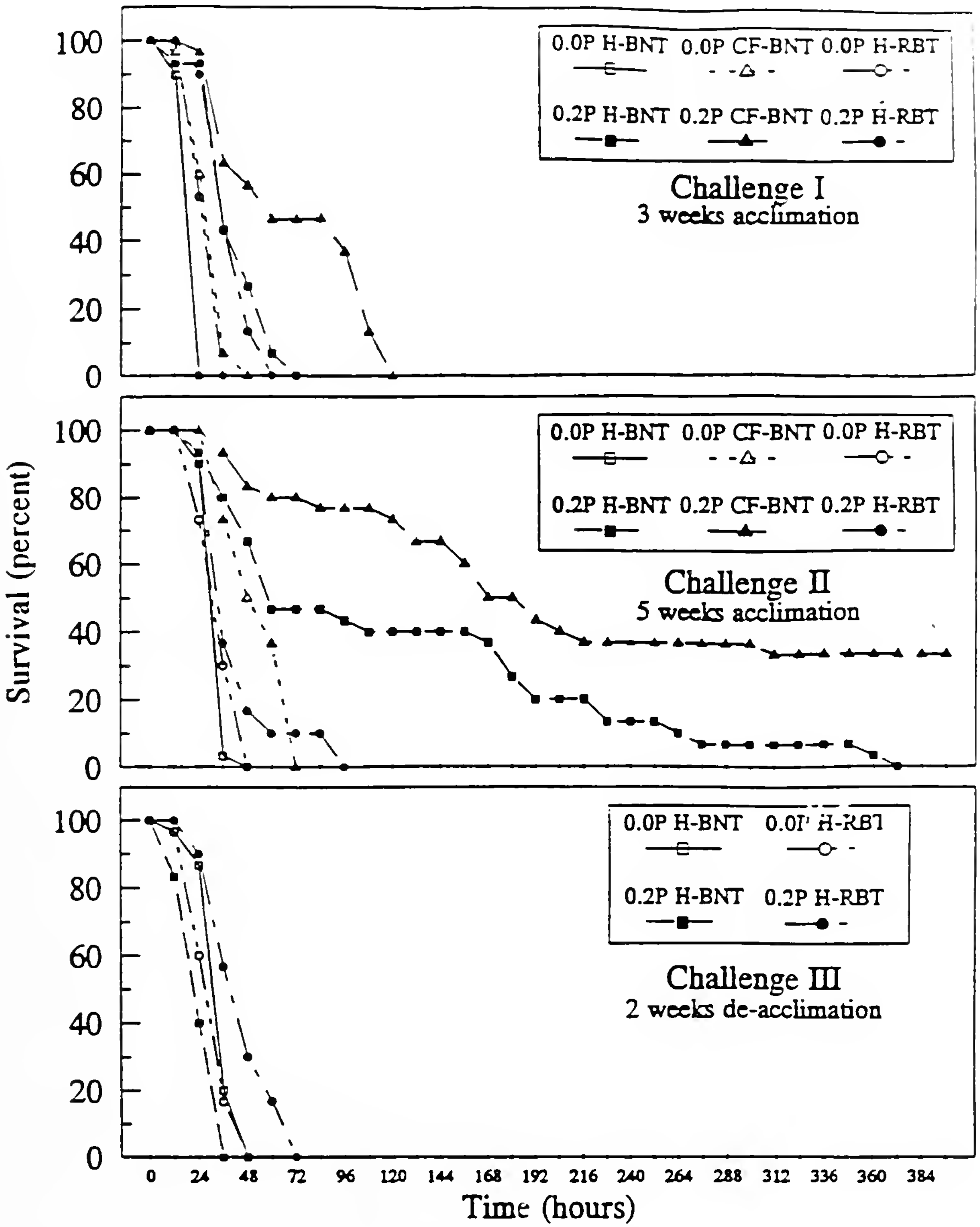

Figure 6-7. **Cumulative Percent Survival During Challenge Periods.** H-BNT = hatchery brown trout, CF-BNT = Clark Fork brown trout, H-RBT = hatchery rainbow trout. Source: Appendix C.

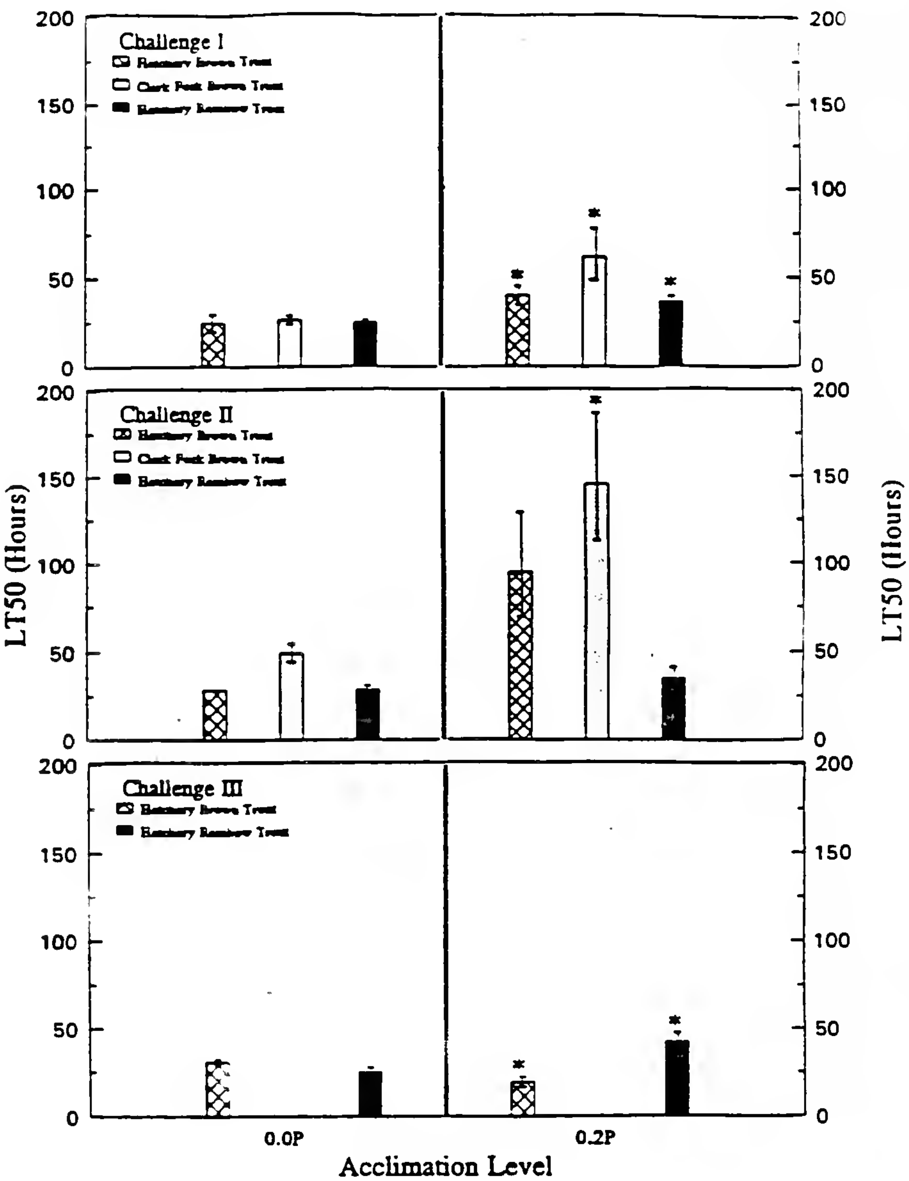

Figure 6-8. **Median Lethal Time (LT50) and 95% Confidence Limits (hours) for Hatchery Brown Trout, Clark Fork River Brown Trout, and Hatchery Rainbow Trout Exposed to Three Experimental Challenges.** Control fish were held in water with no metals present (0P), and test fish were acclimated in water with 0.2P concentrations of metals (46 ppb zinc, 24 ppb c[illegible]per, 0.6 ppb lead, 0.4 ppb cadmium). Fish were then exposed to 1P metals (230 ppb zinc, 120 ppb copper, 3.2 ppb lead, 2.0 ppb cadmium) and mortality monitored. Source: Appendix C.

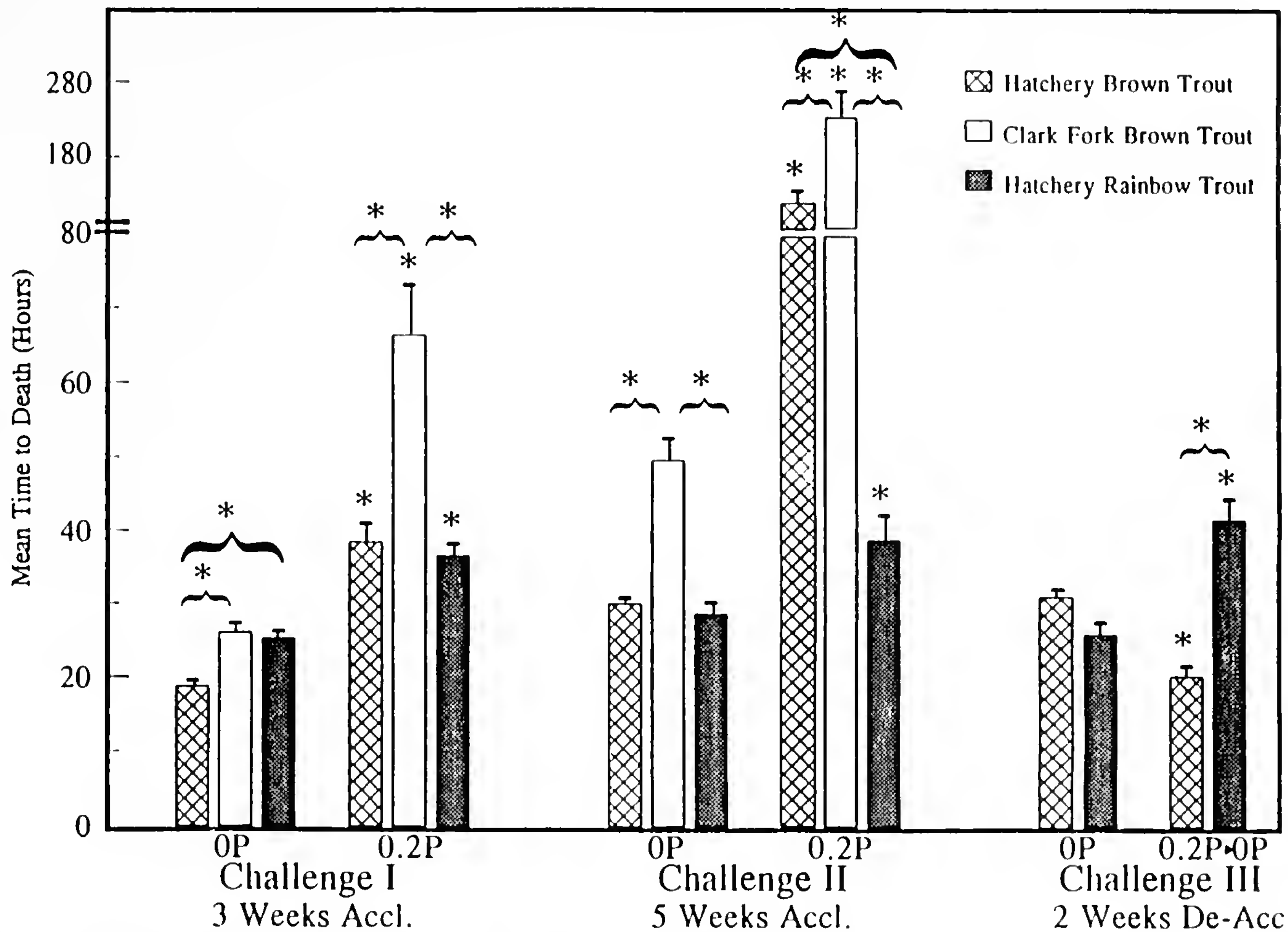

Figure 6-9. **Mean (+1 Standard Error of the Mean) for Time to Death.** Asterisks directly above 0.2P test groups indicate significant difference from the paired 0P group of the same species ($p < 0.05$); an asterisk above a bracket indicates significant difference between the bracketed pair of mean values ($p < 0.05$). Source: Appendix C.

- Acute exposure to cadmium, copper, lead, and zinc caused significant mortality to hatchery rainbow and brown trout, as well as Clark Fork River brown trout, at concentrations frequently observed in the Clark Fork River and Silver Bow Creek.

- Prior to acclimation, the order of sensitivity to metals was found to be Clark Fork River brown trout > hatchery brown trout > rainbow trout.

- All three species/stocks demonstrated increased resistance to metals following acclimation to low levels of metals, with the order of sensitivity being reversed post-acclimation: rainbow trout > hatchery brown trout ≈ Clark Fork River brown trout. This ability to acclimate may help explain the presence of fish in the Clark Fork River (although at greatly reduced numbers relative to baseline conditions).

In addition to the above conclusions, it is important to note that reduced growth has been identified as an effect of sublethal metal exposures (see Section 6.4.6). As described in Appendix C, acclimation to metals involves a metabolic "cost" to fish; this metabolic cost has been associated with reduced growth in the scientific literature. These conclusions are consistent with the pattern of reduced growth that was observed in laboratory feeding studies (again, see Section 6.4.6). Hence, the ability to acclimate to metals may afford a somewhat enhanced ability to resist metals exposures over the short term. However, over the long term, the metabolic costs associated with structural, physiological, and biochemical resistance to metals may ultimately reduce an organism's ability to survive in the wild.

6.4.5 Category of Injury: Behavioral Abnormality/Avoidance

Both laboratory and field studies have shown that fish actively avoid harmful environmental conditions. Threshold concentrations of substances such as carbon dioxide, ammonia, copper, and lead have been established based on the ability of fish to avoid the substances (Rice, 1973; Beitinger and Freeman, 1983; Gunn and Noakes, 1986; Hartwell *et al.*, 1987; Hartwell *et al.*, 1989). Salmonids (trout and salmon) have been shown to avoid dissolved copper concentrations as low as 0.1 parts per billion (Folmar, 1976). Releases of copper and zinc from a mine drainage into a salmon spawning tributary resulted in 10% to 22% repulsion of ascending salmon in four consecutive years, compared to 1% to 3% repulsion prior to the mine drainage release (Saunders and Sprague, 1967). Avoidance behaviors in the Clark Fork River may impede movement of trout from tributary streams into the Clark Fork River for rearing purposes, and may at times cause fish in the Clark Fork River to move into tributaries which, themselves, have limited available habitat. Hence, avoidance responses can, in part, cause reductions in trout populations.

To determine whether brown and rainbow trout avoid, and hence are injured by, the hazardous substances to which they are exposed in the surface water of the Clark Fork River, laboratory avoidance tests were performed using simulated Clark Fork River and control water (Appendix D[7]). Following is a brief summary of these laboratory tests.

As described in Chapter 4.0, concentrations of hazardous substances in Clark Fork River water frequently exceed ambient water quality criteria (AWQC) set by the U.S. EPA. The chronic AWQC values (100 ppm hardness as $CaCO_3$) for cadmium, copper, and lead, and 45% of the chronic AWQC for zinc, were used to represent ambient spring conditions in the Clark Fork River (equivalent to 1.1 ppb cadmium, 12 ppb copper, 3.2 ppb lead, and 50 ppb zinc). In previous experiments, these concentrations have been determined to be appropriate for simulating Clark Fork River conditions by U. S. EPA, ARCO, and U.S. Fish and Wildlife investigators (Environmental Toxicology, 1991; U.S. FWS, 1991).

In the avoidance testing, the above metals concentrations were defined as the "1X" concentration.[8] Brown and rainbow trout were exposed to 0X (control), 0.1X, 0.5X, 1X, 2X, 4X, and 10X concentrations of hazardous substances in a chamber with control water on one side and test water on the other side (see Appendix D). Avoidance responses were assessed by quantifying the amount of time a fish spends in the control water versus the test water containing the hazardous substances.[9]

The results of this testing (Table 6-9a; and Figures 6-10 and 6-11) demonstrated that both brown and rainbow trout significantly avoided hazardous substances representative of Clark Fork River conditions (1X metals concentration). Brown trout significantly avoided test waters at concentrations as low as 0.5X. Brown trout demonstrated a slight reduction of the avoidance response at the 4X and 10X concentrations. This impairment of the avoidance response at elevated concentrations is consistent with the scientific literature. For example, Gardner and LaRoche (1973) and Giattina *et al.* (1982) found that very high concentrations of copper disable or destroy sensory systems leading to decreased avoidance, increased exposure, and mortality.

Rainbow trout were found to demonstrate a greater avoidance "sensitivity" than brown trout (Table 6-9a; Figure 6-11), significantly avoiding water with concentrations of hazardous substances as low as 0.1X. Unlike brown trout, rainbow trout did not show indications of decreased avoidance at elevated metals concentrations.

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[7] "Jackson Protocol P92-40050-10-02: Avoidance," by D.F. Woodward and H.L. Bergman.

[8] Note that the "1X" concentrations used in this study are different than the "1P" concentrations discussed previously.

[9] If no avoidance behavior is manifested, fish will spend, on average, 50% of the time in each end of the avoidance apparatus.

Table 6-9a
Brown and Rainbow Trout Avoidance Responses to Hazardous Substances in Surface Water
(Reference Water = 0X)

Test Water	Mean Time in Test[1] Water (Seconds)	Std. Dev.	Mean Percent of Time in Test Water	Std. Dev.
Brown Trout				
0.0X	601	132	50	11
0.1X	545	95	45	8
0.5X	245*	34	20*	2.8
1.0X	161*	33	13*	2.8
2.0X	96*	45	8*	3.7
4.0X	209*	87	17*	7.3
10.0X	333*	182	28*	15
Rainbow Trout				
0.0X	625	117	52	9.8
0.1X	91*	42	7.6*	3.5
0.5X	23*	6.6	1.9*	0.55
1.0X	25*	11	2.1*	0.9
2.0X	20*	7.9	1.6*	0.66
4.0X	27*	11	2.2*	0.95
10.0X	14*	8.4	1.1*	0.7

Note: 1X metals concentrations represent ambient Clark Fork River conditions as described in the text.

1 Total time of each test = 1,200 seconds.
* Values are significantly lower than control value ($\alpha = 0.05$).
** Values are significantly higher than control value ($\alpha = 0.05$).

Source: Appendix D.

In a separate test, rainbow trout were acclimated to the ambient Clark Fork (1X metals) water for 30 days prior to the avoidance test. During the test, the reference water was 1X instead of 0X, and the test waters were 0X, 1X or 4X metals concentrations. The

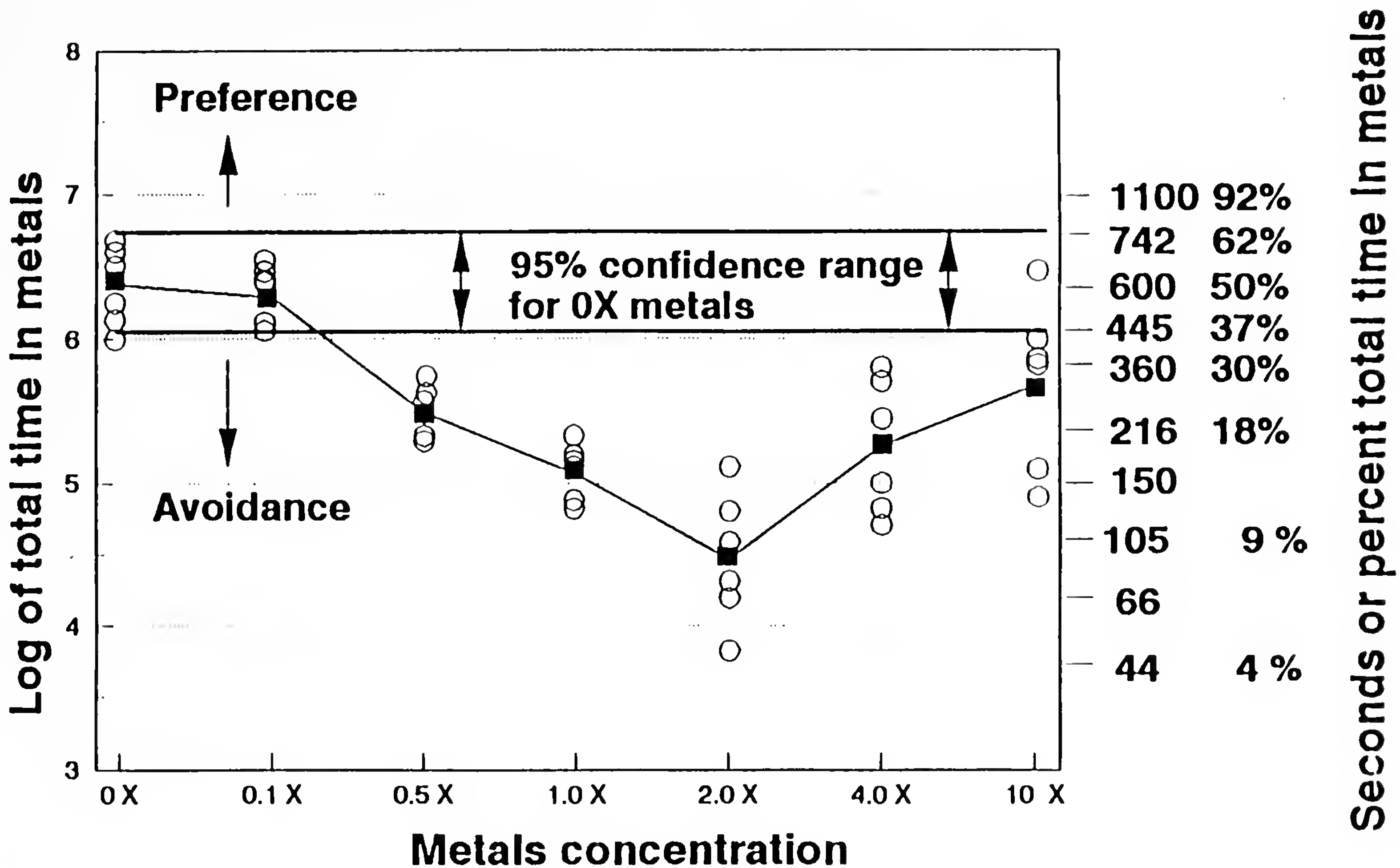

Figure 6-10. **Avoidance Response of Brown Trout to Metals in Water.** "1X" Concentration = 1.1 ppb Cd, 12 ppb Cu, 3.2 ppb Pb, 50 ppb Zn. Source: Appendix D.

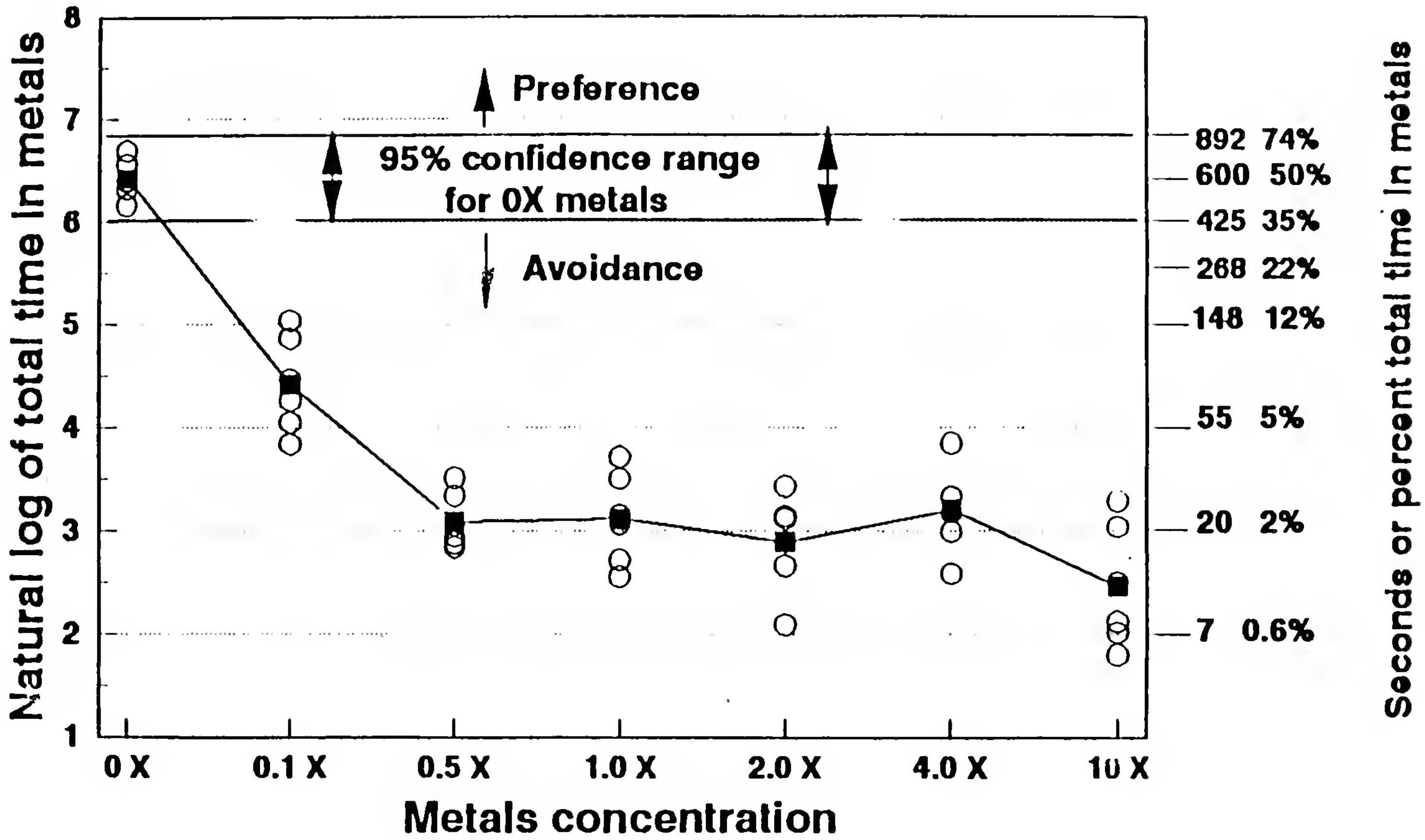

Figure 6-11. **Avoidance Response of Rainbow Trout to Metals in Water.** Source: Appendix D.

acclimation had a dramatic effect on the length of time that a rainbow trout would spend in test water. When both test and reference water were at 1X concentrations, rainbow trout spent roughly 50% of the time in the test water. However, when the "test" water contained 0X metals, the rainbow trout again significantly avoided the 1X exposure, spending 84% of the time in the 0X water (Table 6-9b). When metals concentrations were higher (4X) than in the reference side, acclimated rainbow trout avoided the 4X exposure 70% of the time. Thus, even rainbow trout acclimated to 1X metals for 30 days showed a strong avoidance response.

Summary and Conclusions

Based on the demonstration of behavioral avoidance, both brown and rainbow trout have been injured in the Clark Fork River. The results of these studies indicate that recruitment of trout from unimpacted tributaries (e.g., Rock Creek, Gold Creek, Warm Springs Creek) into the Clark Fork River is likely limited by behavioral avoidance of hazardous substances in the Clark Fork River. Further, the extreme sensitivity of rainbow trout may explain why this species is rarely found in the Clark Fork River upstream of its confluence with Rock Creek. Finally, it should be noted that habitat generally limits the size of trout populations in unpolluted streams (Larkin, 1956; Chapman, 1966). Therefore, avoidance of Clark Fork River water and hence reductions of trout populations in the Clark Fork River should not be offset by increases in tributary populations. Rather, overall populations will decrease.

6.4.6 Category of Injury: Death and Reduced Growth from Food Chain Exposure Pathway

As described in Chapter 5.0, benthic macroinvertebrates of the upper Clark Fork River Basin have accumulated elevated concentrations of hazardous substances as a result of exposure to hazardous substances in bed sediments. Previous studies have shown that dietary uptake of cadmium, copper, lead, and zinc is a predominant pathway of metals accumulation in fish (Crespo *et al.*, 1986; Wekell *et al.*, 1986; Dallinger *et al.*, 1987; Pratap *et al.*, 1989). At sublethal dietary levels, cadmium interferes with calcium and magnesium uptake (Pratap *et al.*, 1989) and copper has been shown to reduce growth in rainbow trout (Lanno *et al.*, 1985; Julshamn *et al.*, 1988). Dietary copper and lead induced morphological and functional alteration of rainbow trout intestine as well (Crespo *et al.*, 1986). A series of studies was conducted to assess the potential effects of this pathway (U.S. FWS and University of Wyoming, 1992, and Appendix E[10]). These studies, described in the following subsections, demonstrate that trout are injured, as

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[10] "Jackson Protocol P92-40050-10-02: Food Chain," by D.F. Woodward, H.L. Bergman, and C.E. Smith.

Table 6-9b
Acclimated Rainbow Trout Avoidance Responses to Hazardous Substances in Surface Water
(Reference Water = 1X)

Test Water	Mean Time in Test[1] Water (Seconds)	Std. Dev.	Mean Percent of Time in Test Water	Std. Dev.
0.0X	1010**	84	84**	7
1.0X	598	72	50	6
4.0X	358*	96	30*	8

Note: 1X metals concentrations represent ambient Clark Fork River conditions as described in the text.

1 Total time of each test = 1,200 seconds.
* Values are significantly lower than control value ($\alpha = 0.05$).
** Values are significantly higher than control value ($\alpha = 0.05$).

Source: Appendix D.

manifested by increased mortality and reduced growth, from exposure to hazardous substances in their diets.

6.4.6.1 Milltown Endangerment Assessment (U.S. FWS and University of Wyoming, 1992)

As part of the Milltown Endangerment Assessment Project (U.S. FWS and University of Wyoming, 1992), rainbow trout were experimentally fed, in controlled laboratory experiments, forage fish and invertebrates collected from the Clark Fork River and the Snake River, WY (the control site). Growth, mortality, and bioaccumulation of hazardous substances in tissues were measured.

Initial Tests

Rainbow trout fry were exposed to combinations of hazardous substances in both their diet and in the water. The water exposures were based on the "1X" metals concentration representative of Clark Fork River conditions described in Section 6.4.5 (1.1 ppb Cd, 12 ppb Cu, 3.2 ppb Pb, and 50 ppb Zn). Trout were exposed to one of three water compositions (0X, 1X, 2X) and fed one of four test diets (Clark Fork River/Control

invertebrates, Clark Fork River/Control forage fish[11]) for 91 days or until 80% mortality had occurred, whichever was first. To represent ambient conditions in the field, the diets were neither vitamin fortified nor pasteurized.

The concentrations (dry weight) of hazardous substances in each of the diets are shown in Table 6-10. The Clark Fork forage fish contained much higher levels of hazardous substances (As, Cd, Cu, Pb, Zn) than did the control fish. Arsenic, cadmium, and lead were below detection limits in the control fish; levels of the hazardous substances in the Clark Fork River forage fish ranged from 90% to over 3,000% greater than the hatchery fish. The Clark Fork River invertebrates had markedly higher levels of the hazardous substances than did the control invertebrates and both of the fish diets. Compared to the control invertebrates, the Clark Fork River invertebrates contained from 214% to over 1,850% greater concentrations of hazardous substance levels.

Rainbow trout fed the Clark Fork River macroinvertebrate diet showed significantly greater mortality after 42 and 91 days than trout fed the control (Snake River) invertebrate diet (Figure 6-12). After 91 days, mortality was greater than 50% for all rainbow trout fed the Clark Fork River invertebrate diet, whereas mortality was less than 20% for the fish fed control (Snake River) invertebrate diets. These results indicate that the hazardous substances in the diet were the cause of the mortality, regardless of the water exposure.

In addition, growth in all fish fed the Clark Fork River invertebrate diet was significantly reduced compared to growth in fish fed the control (Snake River) invertebrate diet regardless of the water exposure (Figure 6-13). Test trout in the 0X water weighed 15% less than control trout in the 0X water after 42 days of exposure, and 39% less after 91 days. Lengths of test trout in all water treatments were significantly lower than in the respective control trout as well.

The presence of hazardous substances in the water made little difference to the mortality or growth of test trout on the Clark Fork River diet and control trout on the Snake River diet. For both control and test trout, mortality was only slightly higher after 91 days in the presence of the 2X metals concentrations than in the 0X or 1X. However, in both cases mortality was lower in the 1X than in the 0X treatments. Thus, hazardous substances in the food appeared to be primarily responsible for the increased mortality and decreased growth in rainbow trout observed in this study.

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[11] The Clark Fork forage fish (white suckers, red-side shiners, and slimy sculpins) and invertebrates (mostly *Hydropsyche* and *Tipula*) were collected near the Warm Springs Ponds; control invertebrates (mostly *Pteronarcys*, *Pteroarcella*, and *Arctopsyche*) were collected from the Snake River near Wilson, WY; control fish were obtained from the Jackson, WY fish hatchery.

Table 6-10
Hazardous Substances in Fish and Invertebrates
(concentration in ppm, dry weight)

Diet	Arsenic	Cadmium	Copper	Lead	Zinc
Jackson (WY) hatchery fish (control)	<2.1	<0.082	4.6	<1.7	109
Clark Fork River forage fish	6.9	0.45	39.1	3.27	218
Snake river (control) invertebrates	4.0	0.4	16.4	<1.7	140
Clark Fork River invertebrates	53	3.9	460	40	640
Biodiet hatchery food (control)	2.06	0.37	9.0	0.27	138
Fortified Clark Fork River forage fish	4.0	0.35	65	5.3	442
Fortified Turah Bridge invertebrates (control)	5.0	1.2	110	9.7	659
Fortified Clark Fork River invertebrates	43	2.4	417	29	1,076

Source: U.S. FWS and University of Wyoming, 1992.

After 91 days of testing, histopathological examinations were performed on surviving fish. These examinations revealed healthy livers in trout on the Snake River invertebrate diet, whereas livers of trout on the Clark Fork River invertebrate diet showed signs of degeneration (see Section 6.4.7). Tissue concentrations of hazardous substances were also significantly higher in test trout on the Clark Fork River invertebrate diet than in control trout on the Snake River invertebrate diet, indicating that hazardous substances in the diets are biologically "available" and are accumulated by fish. After 91 days of exposure, copper in whole body tissue was over ten times higher in test fish than in control fish, and arsenic ranged from six to ten times higher. The water treatments in which fish were held did not make a significant difference in the bioaccumulation of copper or arsenic. Cadmium concentrations in test fish were significantly higher than in control fish in both diet-only and water-only exposures. When exposed to both contaminated water and contaminated diet, the resulting cadmium residue in whole body tissue was significantly greater than in either water or dietary exposure alone, and was much greater than in fish with no exposure at all. Lead residues were also affected by the water treatment. Whole body lead concentrations were not significantly different in test trout exposed to contaminated diet or contaminated water alone; however, trout exposed to both contaminated diet and water had significantly higher lead residues than did unexposed control fish.

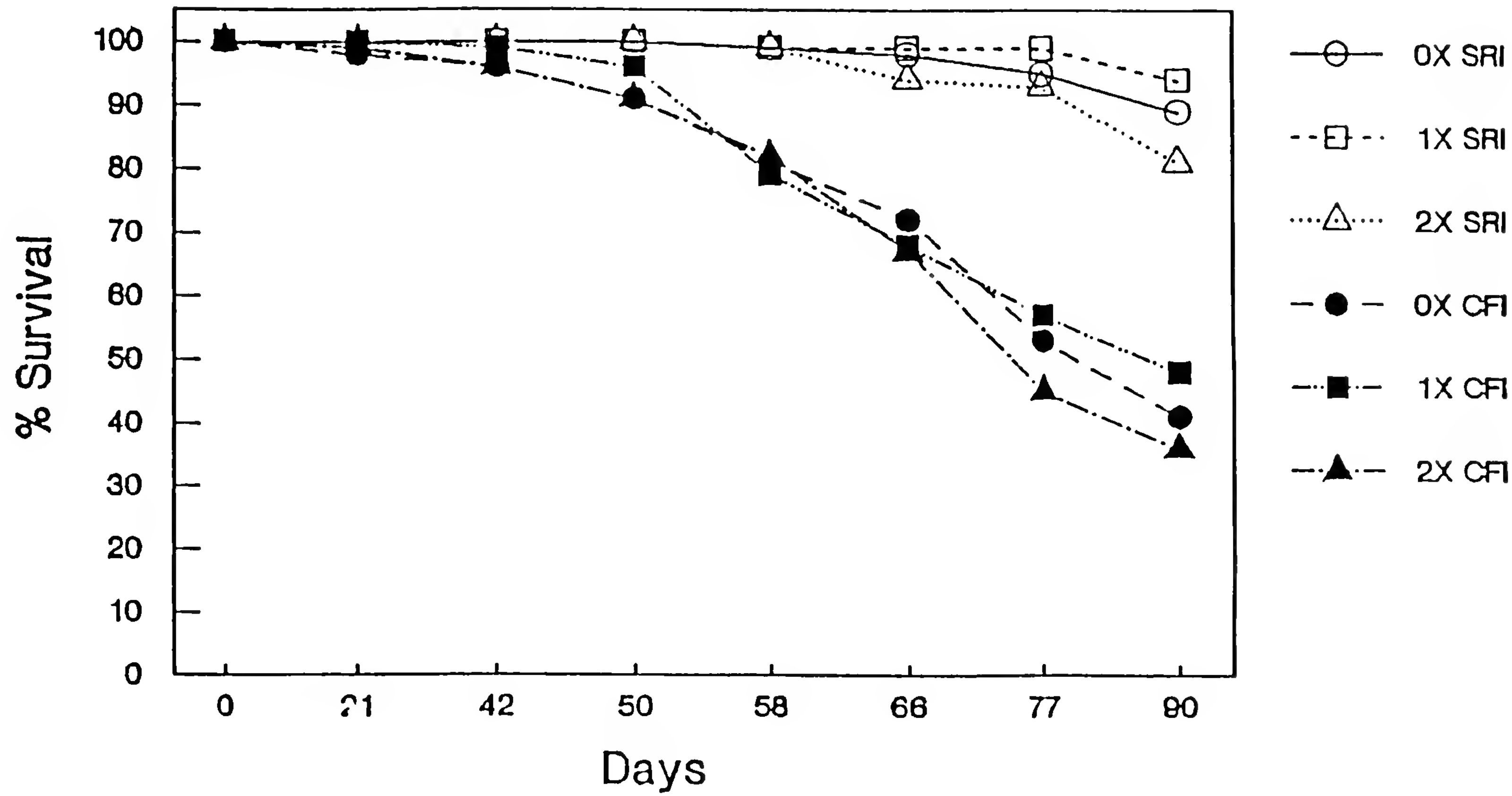

Figure 6-12. **Survival of Rainbow Trout Exposed to Metals in Water (0X, 1X, 2X) and Food [Clark Fork River Invertebrates (CFI) and Snake River (Control) Invertebrates (SRI)].** Source: U.S. FWS and University of Wyoming, 1992.

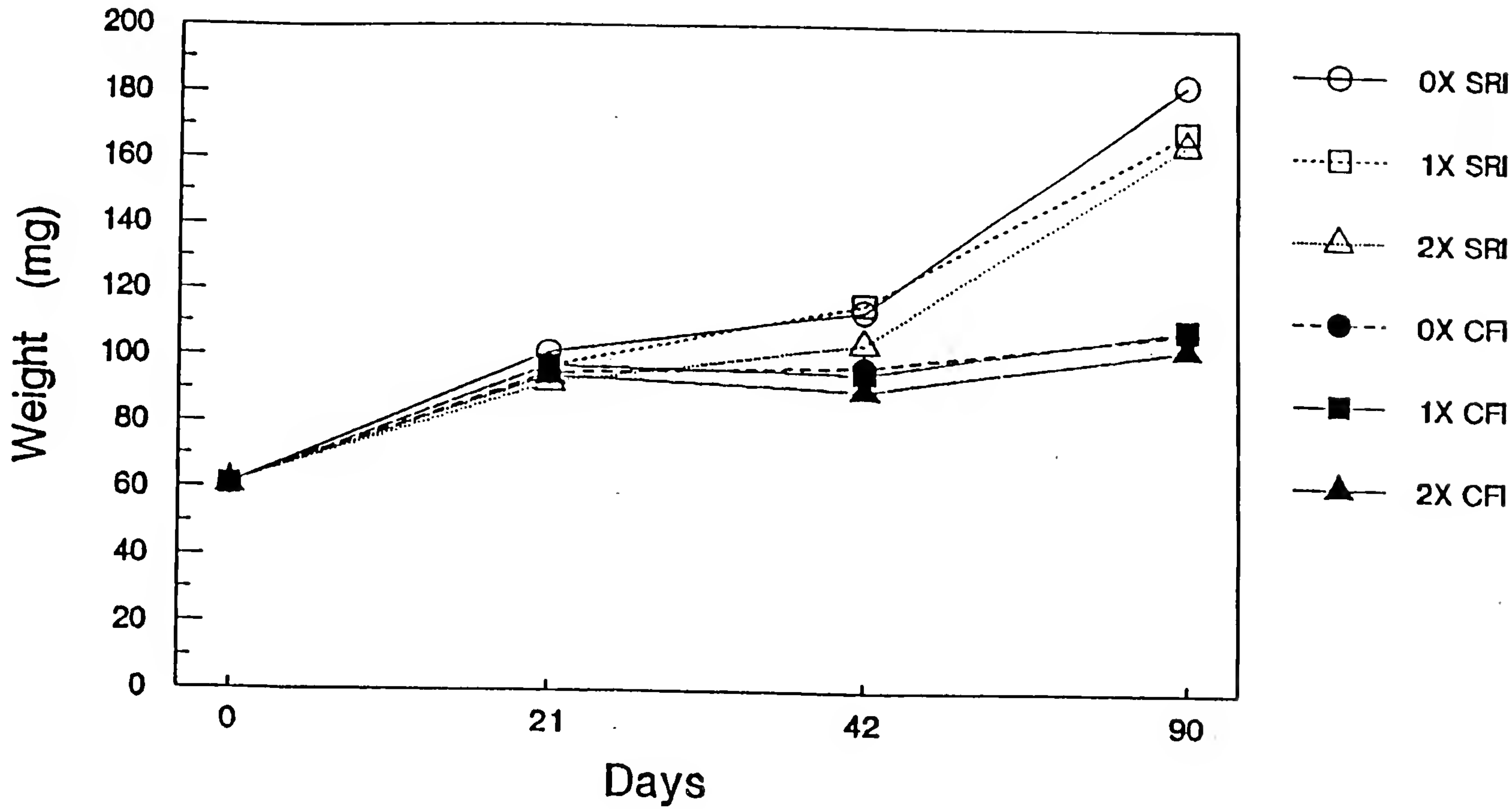

Figure 6-13. **Growth of Rainbow Trout Exposed to Metals in Water (0X, 1X, 2X) and Food [Clark Fork River Invertebrates (CFI) and Snake River (Control) Invertebrates (SRI)].** Source: U.S. FWS and University of Wyoming, 1992.

The results of the tests using contaminated forage fish was less conclusive than with the invertebrates. Although mortality rates exceeding 80% were observed in all three of the test waters, it was postulated that the mortality may have been caused by malnutrition rather than by exposure to hazardous substances (U.S. FWS and University of Wyoming, 1992).

Fortified Diets

A separate set of tests were conducted using nutrient-fortified and pasteurized Clark Fork forage fish and invertebrates collected from both the Warm Springs area and the Turah Bridge area to ensure that dietary effects were not caused by undernourishment. The fortified diets were dried and pelletized, reducing the percent moisture from near 90% to between 5% and 8%. The nutrient-fortified diets showed a similar pattern of elevated hazardous substance concentrations in Clark Fork River (Warm Springs) diets as did the unfortified diets. The nutrient-fortified Turah Bridge (control) invertebrates had far lower concentrations of hazardous substances in tissues than the Clark Fork River (Warm Springs) invertebrates (Table 6-10); therefore, these invertebrates were considered to be a "control" diet group. However, as shown in Chapter 5.0 (Macroinvertebrates), and when compared to the Snake River controls, Turah Bridge invertebrates represent an extremely conservative control group, because the hazardous substance levels in their tissues are well above baseline levels. Rainbow trout in three different water exposures were fed one of four diets (Clark Fork River forage fish, Clark Fork River invertebrates, control invertebrates, and Biodiet, a stock hatchery trout food used as a control). The resulting *growth reductions* were very similar to the tests without the fortification (Table 6-11); however, in the fortified tests no significant mortality was observed.

6.4.6.2 Food Chain Study for Clark Fork River NRDA

A similar series of food-chain exposure tests were performed as part of the Clark Fork River NRDA. The differences between the previous Milltown Endangerment work and the NRDA food chain studies are (1) the NRDA work included brown trout as well as rainbow trout, (2) diets consisted only of nutrient-enhanced and pasteurized Clark Fork River invertebrates, and (3) water treatments consisted only of the 0X and 1X metals concentrations. Appendix E details the methods and results of these tests. A summary of these tests follows.

Macroinvertebrates were collected at three locations in the Clark Fork River: 2 km below Warm Springs Creek, 5 km below Gold Creek, and 2 km above Turah Bridge (Figure 6-14). These invertebrates, processed and pelletized along with nutritional supplements, were fed to both brown and rainbow trout for 88 days. Trout were held in water that simulated ambient Clark Fork conditions (1X) (X = 1.1 ppb Cd, 12 ppb Cu,

Table 6-11
Mean Lengths (mm) and Weights (g) of Rainbow Trout on Nutrient-Enhanced and Pasteurized Diets from the Clark Fork River, with Stock Hatchery Food as a Control

Diet	Day 43		Day 80	
	Weight	Length	Weight	Length
Biodiet fish food (control)	217	30	854	45
Clark Fork River forage fish	228	30	806	44
Control (Turah Bridge) invertebrates	216	30	730**	43**
Clark Fork River (Warm Springs) invertebrates	152*	27*	410*	37*

* Significantly smaller ($\alpha = 0.05$) than any of the other three diets.
** Significantly smaller ($\alpha = 0.05$) than the Biodiet and forage fish; significantly larger than the Warm Springs invertebrate diet.

Source: U.S. FWS and University of Wyoming, 1992.

3.2 ppb Pb, and 50 ppb Zn), while others were held in water without the metals (0X). The Turah Bridge diet again was used as a conservative control diet. As mentioned earlier, this control is conservative because bed sediments near Turah Bridge are contaminated with hazardous substances carried downstream (see Chapter 3.0 - Sediments), and macroinvertebrates from Turah Bridge contain substantially higher hazardous substance concentrations than baseline concentrations in Snake River (WY) or Rock Creek (MT) invertebrates (see Chapter 5.0 - Macroinvertebrates).

The three invertebrate diets had similar nutritional composition because of the nutrient fortification. However, the amount of accumulated metals in the invertebrates was much higher in the Warm Springs and Gold Creek invertebrates than in those from Turah Bridge. Arsenic, copper, and lead levels in the upstream organisms (Warm Springs and Gold Creek) were more than twice the levels in the Turah Bridge organisms (Table 6-12). Cadmium was detected in Warm Springs organisms only. Although the Warm Springs invertebrates used in the Milltown Endangerment Assessment contained greater levels of hazardous substances than those in this study, high variability in metals concentrations in invertebrates has been documented in other studies and should not be considered anomalous (see Chapter 5.0 - Macroinvertebrates). Despite the lower levels of hazardous substances in these Warm Springs invertebrates, the levels were still much higher than in the Turah Bridge invertebrates.

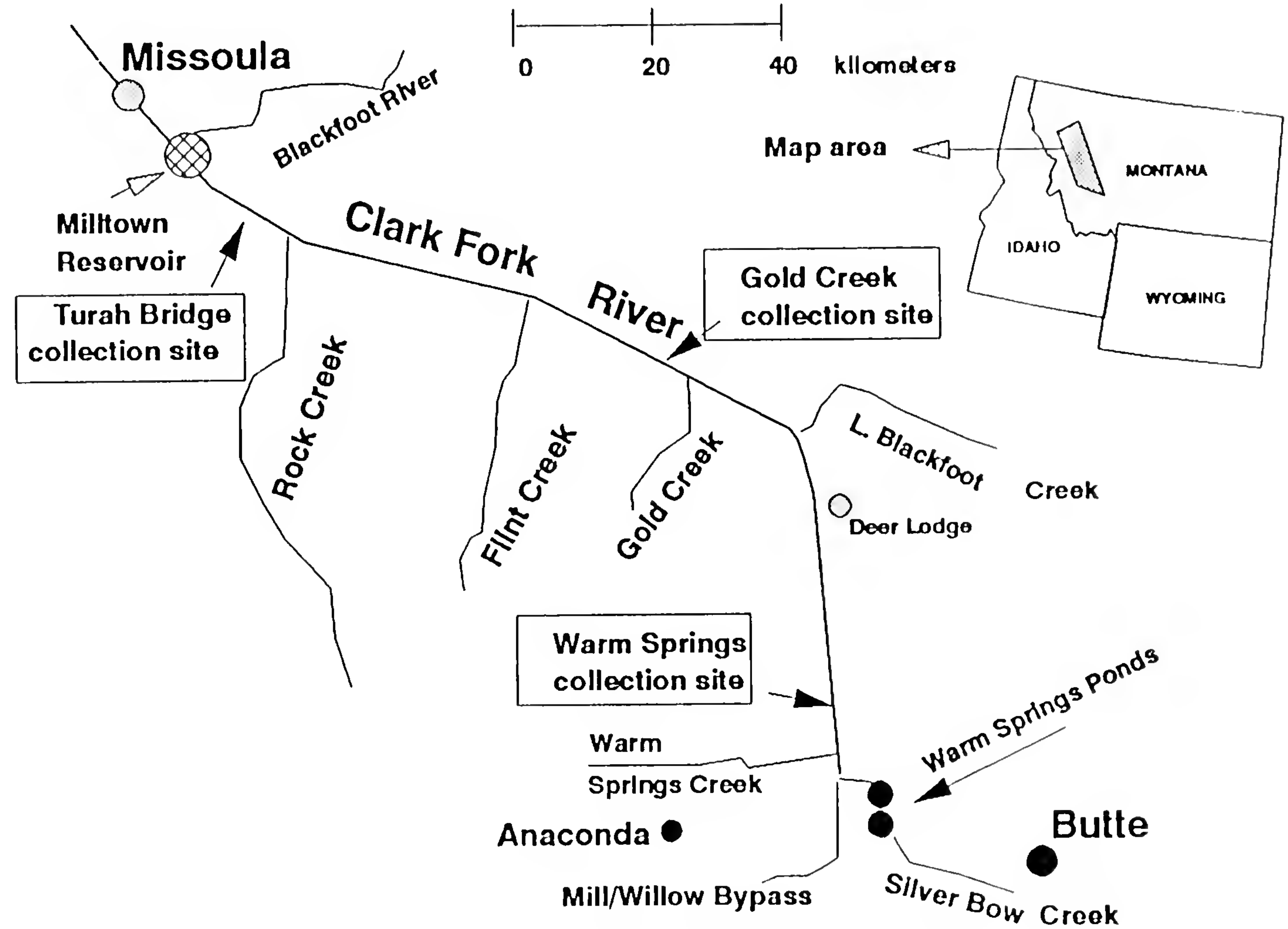

Figure 6-14. **Location of Macroinvertebrate Sampling Sites in the Clark Fork River for Food-Chain Studies.** Source: Appendix E.

Table 6-12
Hazardous Substances (ppm) in Clark Fork River Invertebrate Diets

Location	Arsenic	Cadmium	Copper	Lead	Zinc
Turah Bridge	6.5 (6.9)	<0.009 (<0.010)	87 (92)	6.9 (7.3)	616 (655)
Gold Creek	10 (11)	<0.009 (<0.010)	178 (190)	15 (16)	650 (694)
Warm Springs	19 (21)	0.3 (0.3)	174 (190)	15 (16)	648 (707)

Note: Mean levels of hazardous substances in nutrient-fortified and pelletized Clark Fork River invertebrates collected from three different locations. The top number is the mean concentration in ppm wet weight. The number in parenthesis is the dry weight equivalent (ppm), based on the percentage of moisture in sample.

Source: Appendix E.

Lengths and weights of brown trout were recorded after 26 days, 52 days, and 88 days posthatch, while lengths and weights of rainbow trout were recorded at 18 days, 53 days, and 88 days posthatch. Comparisons were made between the growth of fish fed the three different diets in both contaminated (1X) and uncontaminated (0X) water.

As described in Appendix E, both lengths and weights of brown trout were found to be significantly reduced ($\alpha = 0.05$) in the two upstream diets compared to the Turah Bridge (control) diet (Table 6-13). Weights were significantly lower in all brown trout fed the Gold Creek and Warm Springs diet at days 26, 52, and 88 in both contaminated and uncontaminated water (0X). After 88 days, brown trout fed the Warm Springs diet weighed 39% less than those fed the Turah Bridge control diet in 0X water and 32% less than those fed the Turah Bridge control diet in 1X water. Moreover, exposure to both the contaminated diets and the contaminated (1X) water had a greater effect on growth than exposure to the contaminated diet alone (0X water). As shown in Table 6-13, weights and lengths of the fish fed all three diets were significantly reduced after 52 and 88 days in the 1X water relative to the 0X exposure. Indeed, even the fish fed the control diet (Turah Bridge) demonstrated a 25% reduction in weight and a 10% reduction in length when exposed to the 1X water concentration relative to the 0X water concentration.

Rainbow trout followed the same trend as the brown trout. Rainbow trout fed Warm Springs and Gold Creek diets had significantly reduced growth relative to those fed the Turah Bridge control diet after 53 and 88 days (Table 6-13). Figure 6-15 shows the visible size reduction in rainbow trout fed the contaminated invertebrate diet. However,

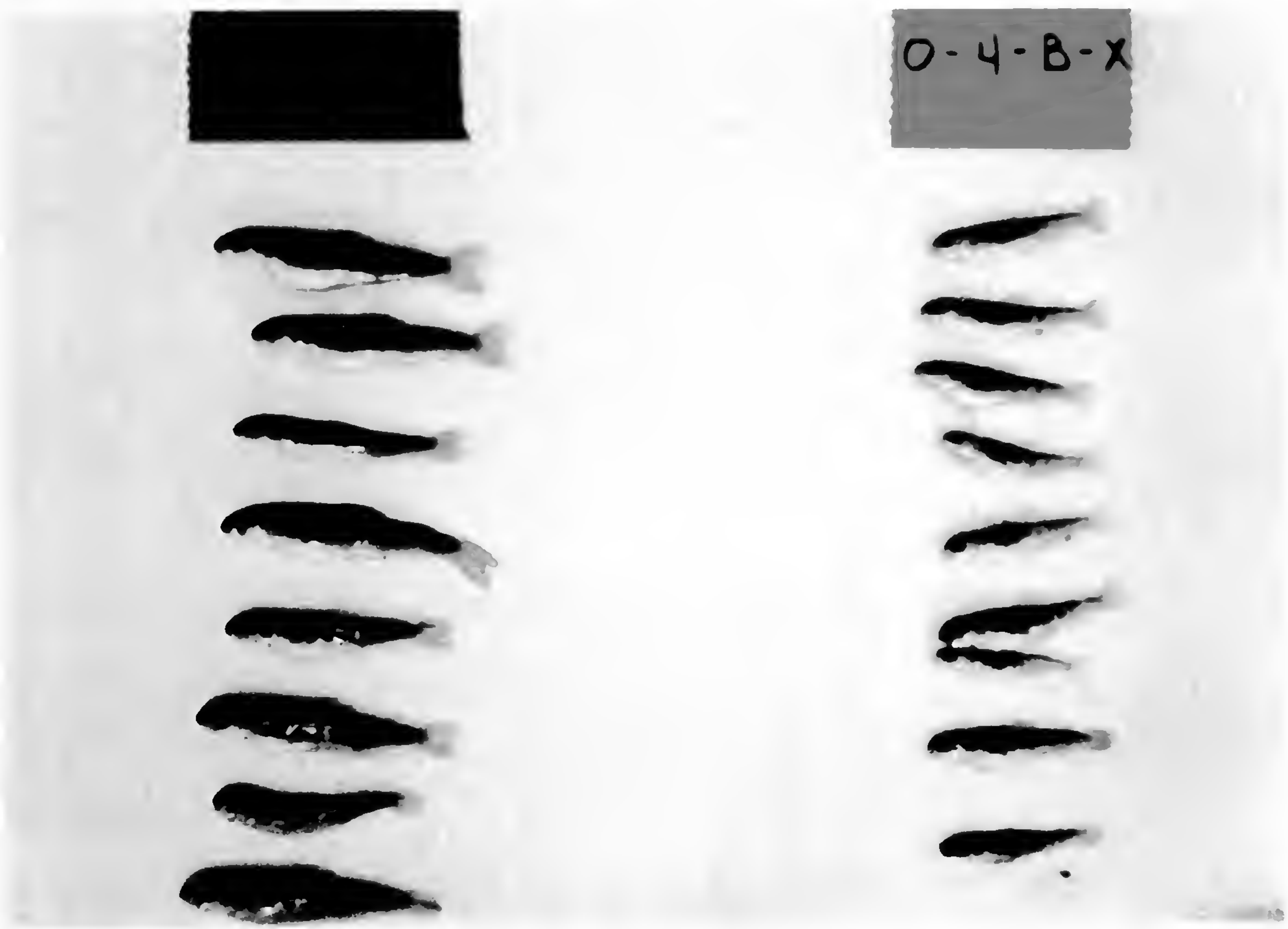

Figure 6-15. Visible Differences in Rainbow Trout Growth after 88 d in 0X Test Water When Fed Warm Springs Invertebrates (Right Column) versus Turah Bridge (Control) Invertebrates (Left Column). Source: Appendix E.

Table 6-13
Trout Growth Following Exposure to Metals-Contaminated Invertebrate Diet and Water

Test Diet/Water	Weight (mg) Day 26	Weight (mg) Day 52	Weight (mg) Day 88	Length (mm) Day 26	Length (mm) Day 52	Length (mm) Day 88
Brown Trout, 0X Water						
Turah Bridge (control)	74 (3.3)	175[a,*] (12)	568[a] (22)	23 (0.28)	28[a] (0.62)	40[a] (0.75)
Gold Creek	70 (2.5)	107[b] (5.8)	347[b] (9.7)	22 (0.35)	25[b] (0.47)	34[b] (0.29)
Warm Springs	68 (1.5)	112[b] (3.2)	344[b] (25)	22 (0.25)	25[b] (0.28)	33[b] (0.72)
Brown Trout, 1X Water						
Turah Bridge (control)	68 (1.9)	130[c] (10)	421[c] (59)	22 (0.2)	26[c] (0.4)	36[c] (1.6)
Gold Creek	67 (1.9)	94[d] (3.8)	267[d] (27)	22 (0.3)	24[d] (0.2)	31[d] (0.9)
Warm Springs	66 (1.0)	87[d] (15)	285[d] (42)	22 (0.2)	24[d] (0.9)	31[d] (1.6)
Rainbow Trout, 0X Water	**Day 18**	**Day 53**	**Day 88**		**Day 53**	**Day 88**
Turah Bridge (control)	94 (1.3)	455[a] (10)	1,408[a] (56)	-	38[a] (0.4)	53[a] (0.7)
Gold Creek	94 (3.2)	227[b] (14)	758[b] (41)	-	30[b] (0.5)	42[b] (0.8)
Warm Springs	92 (1.7)	224[b] (12)	789[b,c] (41)	-	30[b] (0.4)	42[b] (0.6)
Rainbow Trout, 1X Water						
Turah Bridge	92 (2.8)	435[c] (16)	1,374[a] (45)	-	37[a] (0.3)	52[a] (0.5)
Gold Creek	92 (1.8)	225[b] (3.8)	830[b] (9.1)	-	30[b] (0.1)	43[b] (0.1)
Warm Springs	92 (1.6)	233[b] (14)	801[b,c] (36)	-	30[b] (0.5)	42[b] (0.9)

Note: Values are means, with standard deviations in parentheses, n = 4. No length data were collected on Day 18 (rainbow trout).

* Values with same letter are not significantly different ($\alpha = 0.05$).

Source: Appendix E.

for rainbow trout, no growth reductions were observed at the 1X water exposure relative to the diet-only (0X water) exposure.

Length differences, although significant, were less pronounced than weight differences in both brown and rainbow trout, though after 53 and 88 days trout on upstream diets were shorter than those on the Turah Bridge diet (Table 6-11).

Summary and Conclusions

These two sets of studies demonstrate that exposure to hazardous substances via food-chain pathways results in injuries to fish, including both mortality and reduced growth. In the first study (U.S. FWS and University of Wyoming, 1992), exposure to hazardous substances in invertebrates was found to cause both significant mortality and reduced growth. The second study (Appendix E) did not demonstrate significant mortality. However, this latter study was more conservative than the original study because (1) the concentrations of hazardous substances found in the field-collected invertebrates were somewhat lower, and (2) the invertebrates were fortified with vitamins and minerals and pasteurized. As stated in Appendix E:

> "...early life stage trout in the Clark Fork River must sustain themselves on an invertebrate food source that is neither pasteurized nor has vitamins or minerals added. In our attempt to control for causes of mortality other than metals, we probably improved the natural food source and hence reduced the severity of toxicological effects."

6.4.7 Category of Injury: Reduced Growth and Health Impairment

This section describes growth and health impairment injuries to trout as demonstrated in controlled laboratory studies and in free-ranging organisms collected from the Clark Fork River. These injuries included:

- Reduced growth
- Degeneration of the digestive system, as evidenced by pancreatic and intestinal cell degeneration, swollen abdomens, and gut impaction
- Liver cell damage
- Increased lipid peroxidation, an indicator of cell damage

In addition to these measures of physical injury, tissue residues of hazardous substances are presented as indicators of exposure in laboratory and free-ranging organisms. A complete description of these fish health studies is presented in Appendix F.[12]

6.4.7.1 Laboratory Studies

In conjunction with the food-chain studies described above in Section 6.4.6, growth and health impairment injuries were assessed in fish exposed to the contaminated invertebrate diets. At the termination of the feeding studies, eight fish of each species were selected for the following measurements:

- Tissue concentrations of hazardous substances
- Histopathological examination
- Lipid peroxidation
- Autopsy assessment.

Tissue metals concentrations were measured to assess exposure of fish at the tissue level. Histopathological examination was performed to assess the health of gill, liver. kidney, gastrointestinal tract, and pancreatic tissues. Lipid peroxidation was measured because it is an indicator of cell damage. Autopsy assessment was performed to evaluate any abnormalities associated with length, weight, eyes, gills, head, fins, spleen, kidney, liver, and bile. The methods used for the above techniques are described in Appendix F.

Tissue Concentrations of Hazardous Substances

Brown trout fed the contaminated Gold Creek and Warm Springs invertebrate diets accumulated significantly higher concentrations of both copper and lead than those fed the control (Turah Bridge) diet at both the 0X and 1X water exposure (Table 6-14, Figure 6-16). Similarly, both brown and rainbow trout fed the Gold Creek and Warm Springs diets accumulated significantly higher concentrations of arsenic than those fed the control diets at both the 0X and 1X water exposure. Brown and rainbow trout both accumulated significantly greater concentrations of cadmium from the contaminated diets relative to the control diets. However, for brown trout, this accumulation was only significant at the most upstream site (Warm Springs diet) at the 0X water concentration; for rainbow trout, accumulation was only significant at the 1X water concentration.

Histopathological Assessment

As described in both Appendices E and F, brown trout fed the contaminated diets demonstrated physiological abnormalities. These included reduced amounts of zymogen

[12] "Research Report in Injury Determination, Fishery Protocol #2," by H.L. Bergman.

Table 6-14
Whole Body Tissue Concentrations (ppb, wet weight)

Diet	Water	Arsenic	Cadmium	Copper	Lead
Brown Trout					
Turah Bridge (control)	0X	0.19	0.04	2.44	0.19
Gold Creek	0X	0.66[a]	0.05	5.26[a]	0.48[a]
Warm Springs	0X	0.74[a]	0.09[a]	6.80[a]	0.85[a]
Turah Bridge (control)	1X	0.18	0.09[a]	3.53	0.52[a]
Gold Creek	1X	0.71[a,b]	0.13[a,b]	6.88[a,b]	0.88[a,b]
Warm Springs	1X	0.79[a,b]	0.15[a,b]	8.23[a,b]	0.78[a,b]
Rainbow Trout					
Turah Bridge (control)	0X	0.28	0.05	3.08	0.23
Gold Creek	0X	0.58[a]	0.04	3.19	0.19
Warm Springs	0X	0.72[a]	0.04	4.27	0.25
Turah Bridge (control)	1X	0.22	0.14[a]	2.89	0.39
Gold Creek	1X	0.58[a,b]	0.10[a]	3.38	0.21
Warm Springs	1X	0.63[a,b]	0.16[a]	4.01	0.46

[a] = Significantly greater than control/0X
[b] = Significantly greater than control/1X

Source Appendix F.

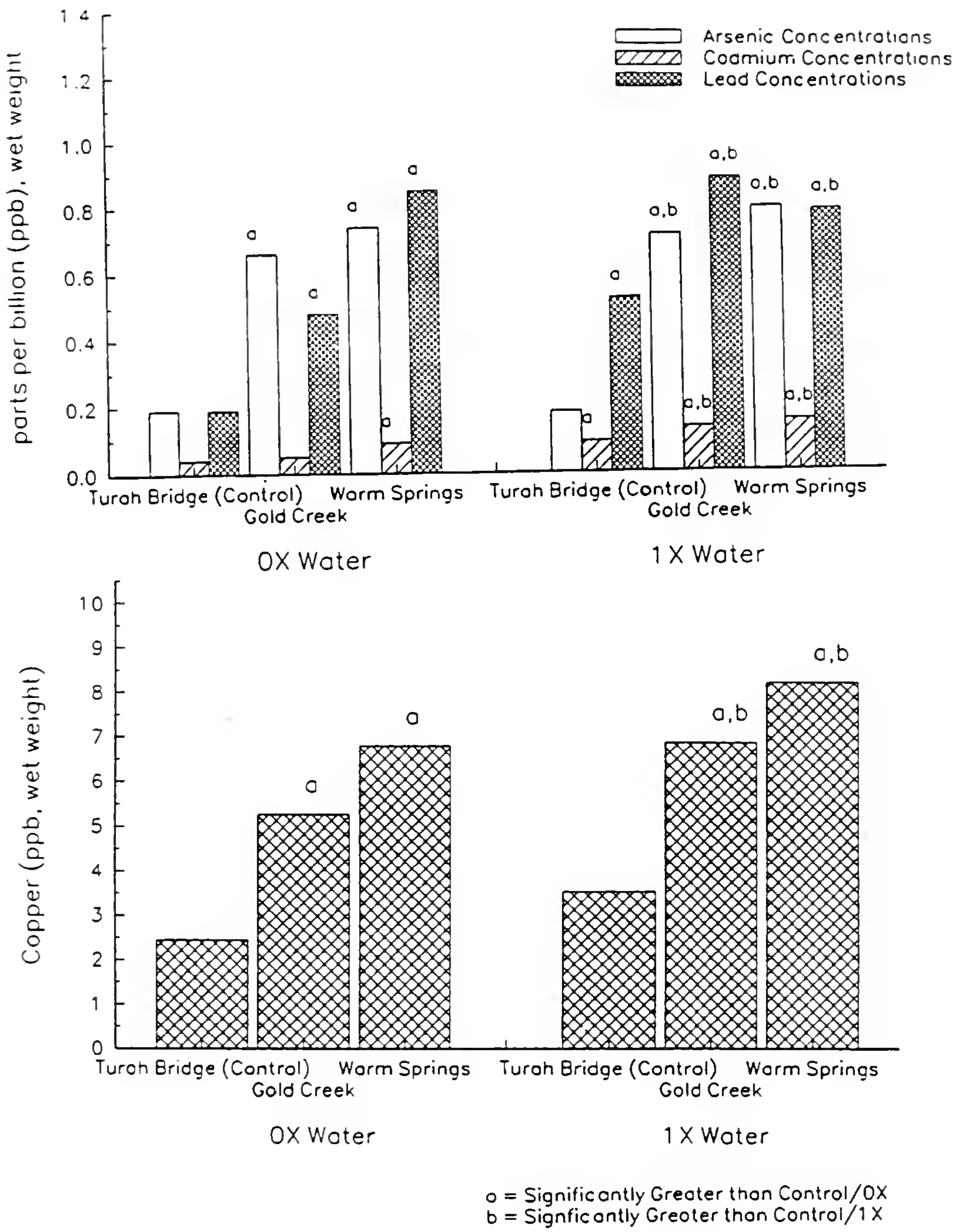

Figure 6-16. Whole Body Concentrations of Hazardous Substances in Trout Fed Contaminated Invertebrate Diets. Source: Appendix E.

— precursors of digestive enzymes commonly found in pancreatic cells — in brown trout fed the contaminated Clark Fork River invertebrates (Warm Springs diet). In addition, degeneration of pancreatic cells was observed in fish fed the Clark Fork River invertebrates (Warm Springs diet). These effects were not observed in rainbow trout. However, rainbow trout demonstrated greatly reduced feeding activity when fed the two upstream Clark Fork River contaminated diets (Warm Springs, Gold Creek). Thus, poor feeding may explain the absence of effects in rainbow trout.

Lipid Peroxidation

Brown trout fed the Clark Fork River/Warm Springs invertebrate diet were found to have greater lipid peroxidation than those fed invertebrates from the downstream sites (Gold Creek and the control, Turah Bridge). Fish fed invertebrates from the Gold Creek location were found to have greater lipid peroxidation than those fed invertebrates from the Turah Bridge control site (Table 6-15). There was no increased lipid peroxidation in rainbow trout. Again, poor feeding may explain the absence of effects in rainbow trout.

Table 6-15
Mean Lipid Peroxidation (standard error in parenthesis) of Brown and Rainbow Trout Fed Invertebrate Diets Collected from the Clark Fork River

Water and Diet	Brown Trout	Rainbow Trout
0X		
Turah Bridge	1.68 (0.15)[a*]	1.39 (0.15)
Gold Creek	2.52 (0.06)[b]	1.22 (0.10)
Warm Springs	3.99 (0.72)[c]	1.52 (0.40)
1X		
Turah Bridge	1.80 (0.09)[a]	0.94 (0.07)
Gold Creek	2.84 (0.45)[a,b]	1.57 (0.23)
Warm Springs	3.85 (0.63)[b,c]	1.68 (0.51)

0X water concentrations contain no metals; 1X water concentrations contain metals simulating Clark Fork River conditions.

* Values with different letters are significantly different ($p < 0.05$).

Source: Appendix F.

Autopsy Assessment

As described in Appendix E, the most apparent physical deformations observed in the autopsy assessment was the appearance of swollen abdomens and gut impaction in brown trout (Figure 6-17). Brown trout fed the contaminated Warm Springs invertebrate demonstrated 4% and 9% occurrence of gut impaction in the 0X and 1X water exposures, respectively. Brown trout fed the contaminated Gold Creek diets demonstrated a 3% occurrence of gut impaction. The condition was not observed in either the Gold Creek/1X water exposure or in any controls (Turah Bridge diets). The condition was not observed in any rainbow trout.

Summary and Conclusions

The results of these studies demonstrate that in laboratory exposures:

- Arsenic, cadmium, copper, and lead concentrations accumulated in the tissues of trout fed contaminated invertebrate diets from the Clark Fork River.

- Water-only exposures resulted in an increase of accumulated cadmium and lead; diet-only exposures resulted in an increase of all four hazardous substances.

- Increased gut impaction, constipation, cell membrane damage (lipid peroxidation), and decreased digestive enzyme production were all observed in brown trout fed the contaminated Warm Springs and Gold Creek diets. Other physical deformations observed in the gastrointestinal tracts of brown and rainbow trout fed the contaminated diets (Warm Springs and Gold Creek) included the sloughing of intestinal mucosal cells. These deformations may explain, in part, the reduced growth observed in these fish because of decreased food assimilation efficiency (Appendix E).

Thus, a consistent pattern of tissue accumulation and physical deformations was observed in trout fed the contaminated invertebrate diets. Again, it should be noted that although many of the same injuries were not observed in rainbow trout, rainbow trout fed the contaminated Gold Creek and Warm Springs diets exhibited reduced feeding activity. This reduced feeding may explain the absence of the injuries observed in rainbow trout.

6.4.7.2 Field Studies

Fish health assessment studies also were performed using fish collected in the field from the Clark Fork River and from two control locations. These field studies using free-

ranging trout demonstrated a similar pattern of fish health degradation as the laboratory studies. This section describes the results of these studies.

As described in Appendix F, brown trout were collected in May 1992 from the Clark Fork River near Warm Springs and near Turah Bridge, as well as from two control locations: the Big Hole River and Rock Creek. Length and weight measurements were taken in the field, and tissues of large intestine, gill, kidney, liver, and pyloric caeca[13] were dissected for examination and analysis. The fish health endpoints assessed using these fish were similar to those used in the laboratory analysis:

- Tissue concentrations of hazardous substances
- Histopathological examination
- Lipid peroxidation
- Autopsy assessment.

In addition, metallothionein (MTN) concentrations (metal-binding enzymes that are produced by fish to detoxify metals) were measured.

Tissue Concentrations of Hazardous Substances

Trout collected from the Clark Fork River near Warm Springs had significantly higher tissue concentrations of copper (in gill, liver, kidney, pyloric caeca, and whole fish), cadmium (gill, liver, kidney, and pyloric caeca), lead (liver), and arsenic (liver, kidney, and pyloric caeca) than baseline conditions (Figures 6-18 to 6-21). In addition, trout collected from the Clark Fork River near Warm Springs also had significantly higher concentrations of hazardous substances than trout collected from the downstream Clark Fork River site near Turah Bridge for copper (gill, liver, kidney, whole fish), cadmium (gill, liver, kidney, pyloric caeca), and arsenic (liver, kidney, pyloric caeca). Trout collected from the downstream Clark Fork River site near Turah Bridge had significantly higher tissue concentrations than baseline for copper (liver, whole fish), cadmium (liver, kidney, pyloric caeca), lead (kidney), and arsenic (kidney).

As described in Appendix F, the copper residues measured in Clark Fork River fish are substantially higher than those reported from various locations in the United States. Schmitt and Brumbaugh (1990, as cited in Appendix F) report a national geometric mean concentration of copper in whole fish of 3.25 μg/g (dry weight), and a national 85th percentile concentration of 5.0 μg/g (dry weight). In contrast, fish collected from the Clark Fork River near Warm Springs had a mean whole body copper concentration of 6.36 μg/g (dry weight). Fish collected from the Clark Fork River near Turah Bridge had

[13] An extension of the small intestine in fish.

Figure 6-17. Impacted Guts in Brown Trout Fed the Warm Springs Invertebrate Diet. (Exposed test fish on left; control fish on right.) Source: Appendix E.

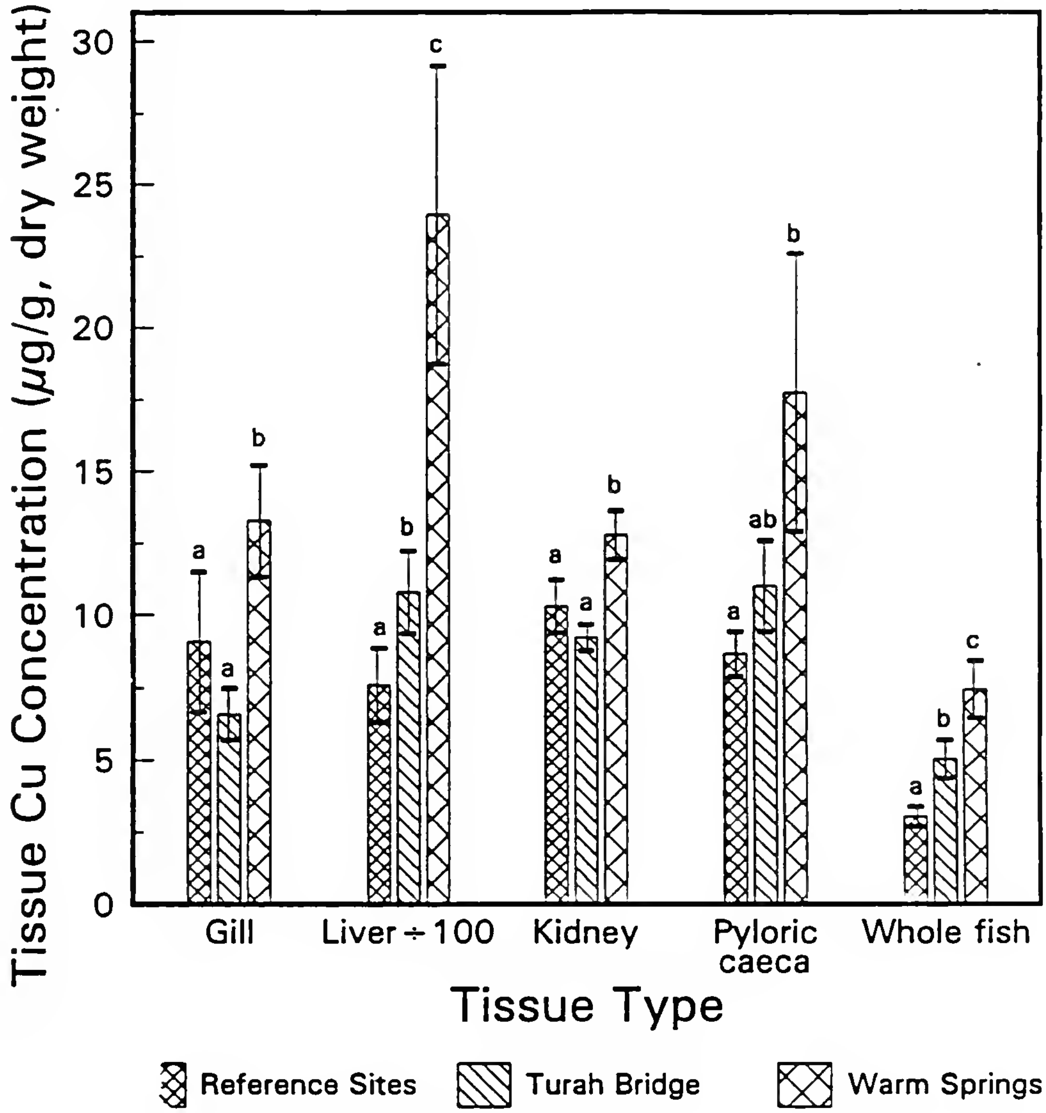

Figure 6-18. **Mean Concentrations (± 1 Std. Error) of Copper in Field-collected Brown Trout from the Clark Fork River (Warm Springs, Turah Bridge) and a Control ("Reference") Site (Rock Creek).** Samples with different letters are significantly different from one another ($p < 0.05$). Source: Appendix F.

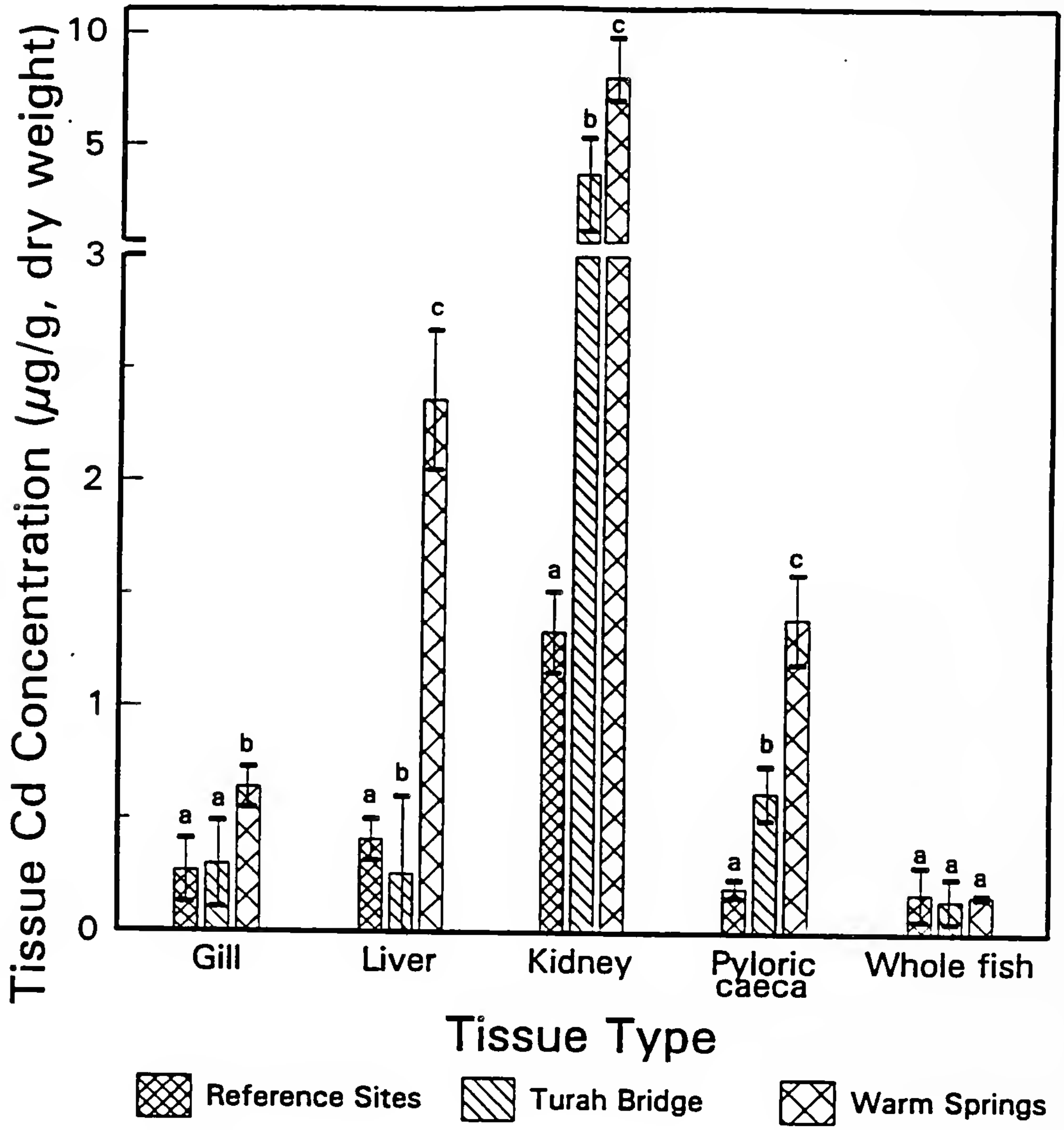

Figure 6-19. Mean Concentrations (± 1 Std. Error) of Cadmium in Field-collected Brown Trout from the Clark Fork River (Warm Springs, Turah Bridge) and a Control ("Reference") Site (Rock Creek). Samples with different letters are significantly different from one another ($p < 0.05$). Source: Appendix F.

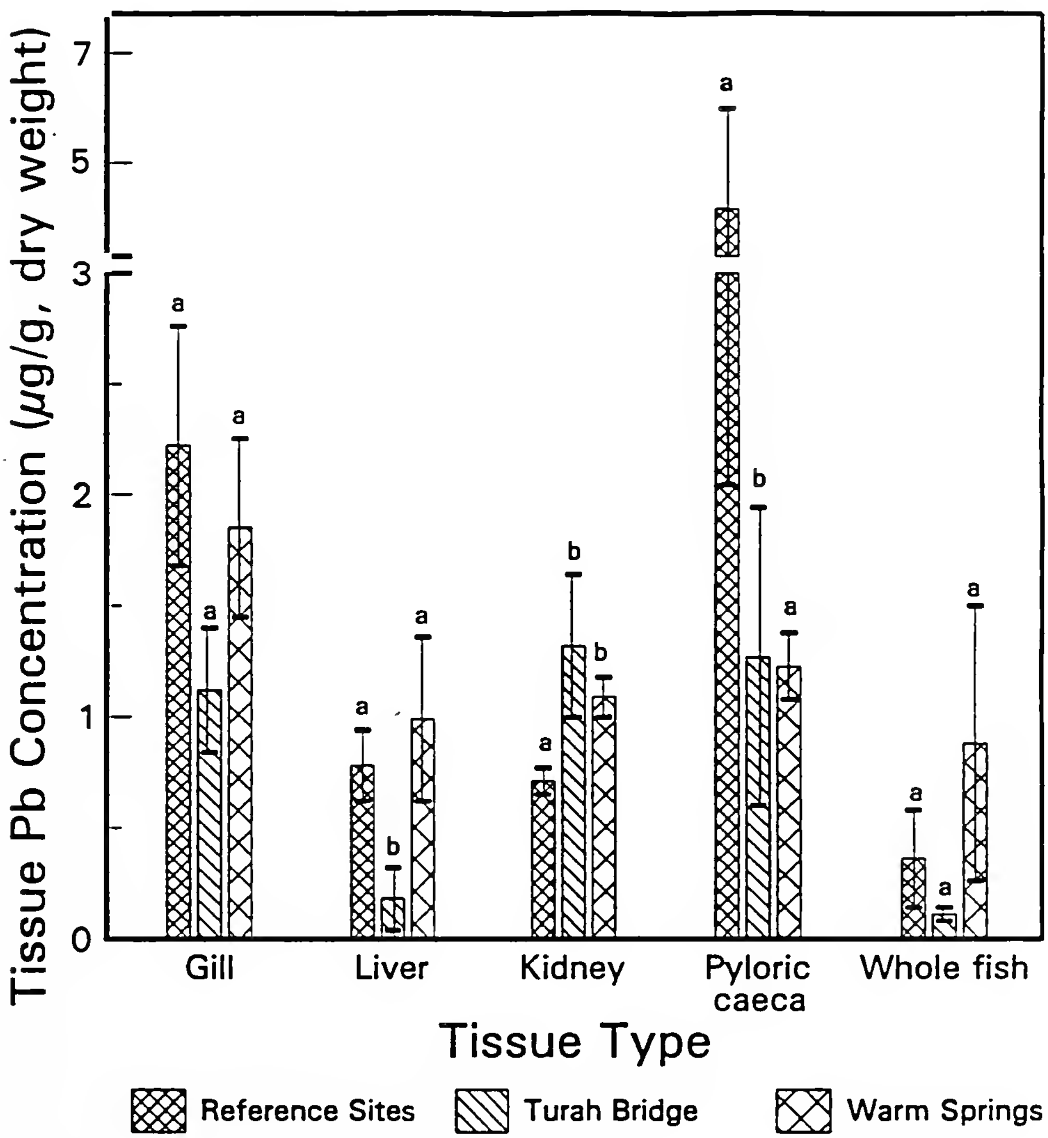

Figure 6-20. **Mean Concentrations (± 1 Std. Error) of Lead in Field-collected Brown Trout from the Clark Fork River (Warm Springs, Turah Bridge) and a Control ("Reference") Site (Rock Creek).** Samples with different letters are significantly different from one another ($p < 0.05$). Source: Appendix F.

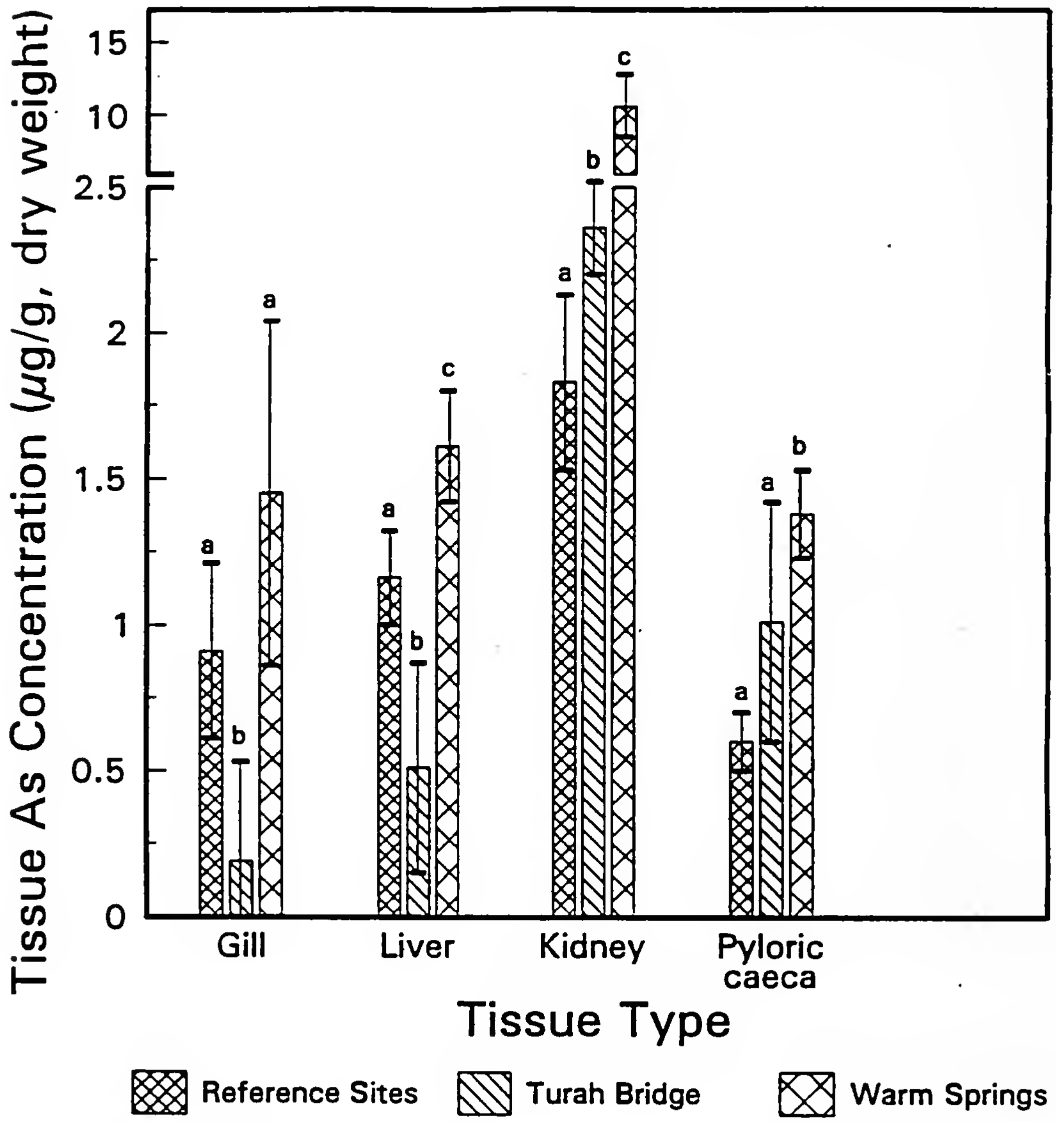

Figure 6-21. **Mean Concentrations (± 1 Std. Error) of Arsenic in Field-collected Brown Trout from the Clark Fork River (Warm Springs, Turah Bridge) and a Control ("Reference") Site (Rock Creek).** Samples with different letters are significantly different from one another ($p < 0.05$). Source: Appendix F.

a mean whole body copper concentration of 4.26 $\mu g/g$ (dry weight). Measured baseline concentrations (Rock Creek and Big Hole River combined) were 3.04 $\mu g/g$ (dry weight) -- approximately the same as the national mean concentration.

As described in Appendix F, copper residues measured in livers from both the Warm Springs and the Turah Bridge fish exceeded liver concentrations that have been shown to impair both growth and reproduction in fish.[14] Finally, the copper residues were lower than those reported for fish collected from the same reaches of river in the mid-1970s. Dent (1974, as cited in Appendix F) reported whole body copper concentrations of 7.2 $\mu g/g$ in the Clark Fork River downstream from Warm Springs, 7.2 $\mu g/g$ near Racktrack, and 7.0 $\mu g/g$ near Rock Creek.

Histopathological Assessment

As described in Appendix F, livers of fish collected from both of the Clark Fork River sites and from the Rock Creek control site exhibited varying amounts of copper inclusions in liver cells, with the number and extent of copper inclusions being Clark Fork River/Warm Springs > Clark Fork River/Turah Bridge > Rock Creek > Big Hole River (no inclusions observed). In addition, irreversible cell damage (nuclear vacuolation of hepatocytes) was also observed, with the number and extent of liver damage being Clark Fork River/Turah Bridge > Clark Fork River/Warm Springs > Rock Creek > Big Hole River (no abnormalities observed).

Lipid Peroxidation

As shown in Figure 6-22, lipid peroxidation in large intestine, liver, and pyloric caeca of fish collected from the Clark Fork River/Warm Springs site was significantly greater than either Turah Bridge or baseline, where baseline conditions were defined by pooling the results from the two control sites, Rock Creek and the Big Hole River. There were no significant differences between Turah Bridge and baseline.

Autopsy Assessment

There were no significant differences observed in any of the autopsy parameters. Although not statistically significant at the 5% level, the mean growth condition factor (KTL) [calculated as $(W \times 10^5)/L^3$, where W = weight (g) and L = length (mm)] in Warm Springs trout was lower than the mean KTL in trout from any of the other three sites. Again, the <u>order</u> of the KTLs was consistent with the degree of site contamination, with Clark Fork River/Warm Springs < Clark Fork River/Turah Bridge < Big Hole River < Rock Creek.

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[14] It should be noted that copper concentrations in livers from control site fish also exceeded this threshold. This emphasizes the conservative nature of the control sites in determining baseline and may explain why no significant growth reductions were observed in the autopsy assessments.

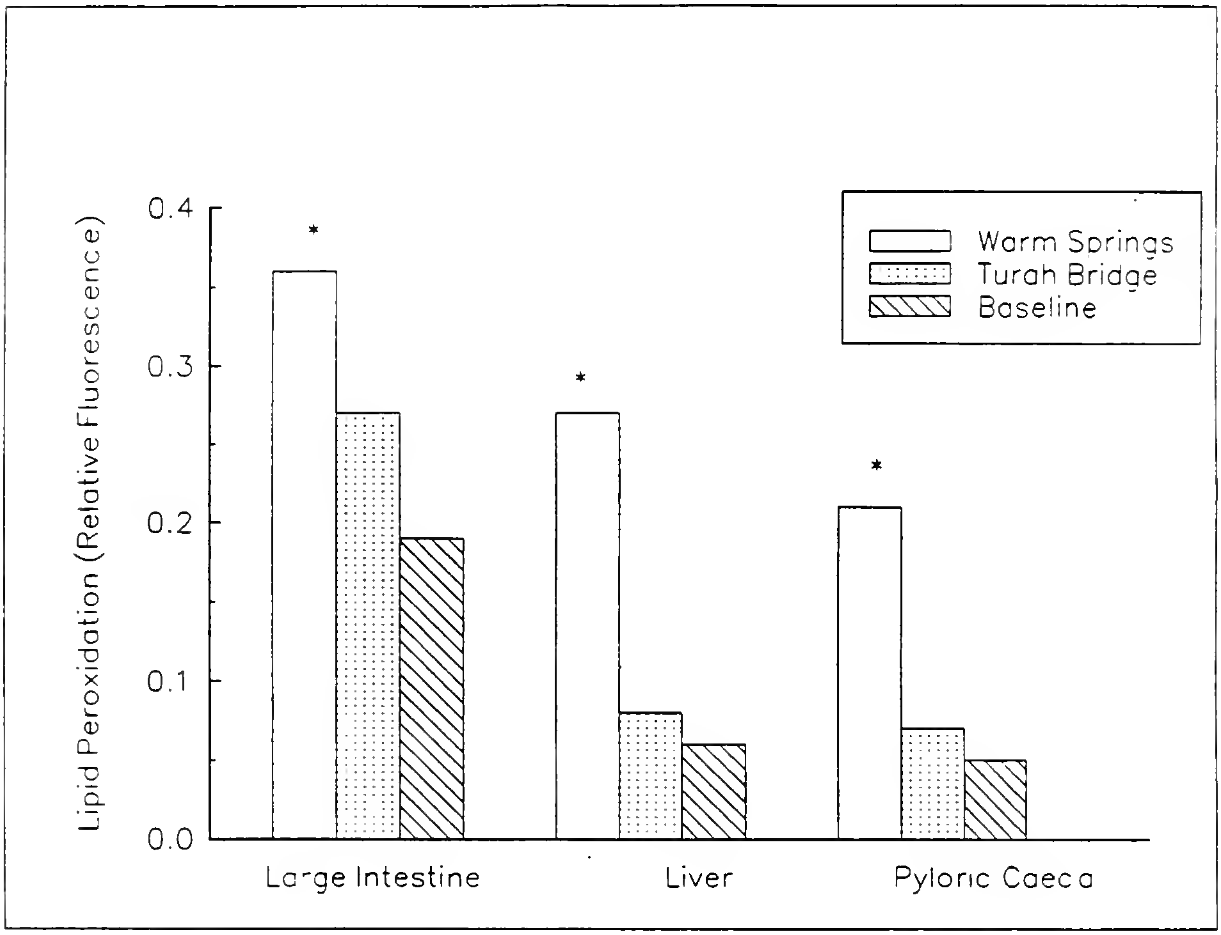

Figure 6-22. **Lipid peroxidation (measured as relative fluorometric intensity) in brown trout collected from the Clark Fork River (Warm Springs and Turah Bridge sites) versus baseline.** Baseline conditions determined from pooled data from two control sites: Big Hole River and Rock Creek. (* indicates significantly different from baseline, $p < 0.05$). Source: Appendix F.

Metallothionein

Increased MTN in fish tissue is an indicator of exposure to high levels of heavy metals, especially copper (McCarter *et al.*, 1982). The levels of MTN in liver tissues of the Warm Springs brown trout were significantly higher than in the Turah Bridge, Big Hole River, or Rock Creek brown trout (Figure 6-23). The MTN levels in the Warm Springs brown trout was more than two times the MTN levels in each of the trout from the other three locations.

Several studies (Dixon and Sprague, 1981a, 1981b, as cited in Appendix F) have linked copper exposure, elevated metallothionein, and reduced growth in rainbow trout. In all exposures where metallothionein was significantly elevated, significant reductions in trout growth were also observed (Dixon and Sprague, 1981a, 1981b, as cited in Appendix F).

Other Health Impairment Indicators

In addition to the above indicators of physiological health impairment, Farag and Bergman (1993, as cited in Appendix F) reported scale loss in 83% of adult rainbow trout fed a diet of contaminated invertebrates collected from the Clark Fork River near the Warm Springs Ponds. Similarly, Tohtz (1992, as cited in Appendix F) observed a high rate of scale regeneration (scales regenerate after being lost) in free-ranging brown trout collected from the Clark Fork River. Scale loss, observed in both laboratory and field studies, may therefore represent a physiological impairment caused by exposure to hazardous substances. It is generally accepted that scale loss can lead to increased susceptibility to disease and parasitism which, in turn, can reduce survivability in the field (Gaines and Rogers, 1975, as cited in Appendix F).

Summary and Conclusions

Overall, the results of the fish health impairment field studies show a similar pattern of hazardous substance accumulation and resulting physiological stress as was shown in the laboratory studies. Specifically:

- Trout collected from the Clark Fork River/Warm Springs site had significantly higher tissue concentrations of copper, cadmium, lead, and arsenic than baseline conditions, as well as significantly higher tissue concentrations of copper, cadmium, and arsenic than the less-contaminated downstream site near Turah Bridge.

- Whole-body copper concentrations at the Clark Fork River/Warm Springs site exceeded the national 85th percentile concentrations. Whole-body concentrations at the Clark Fork River/Turah Bridge site exceeded national mean concentrations.

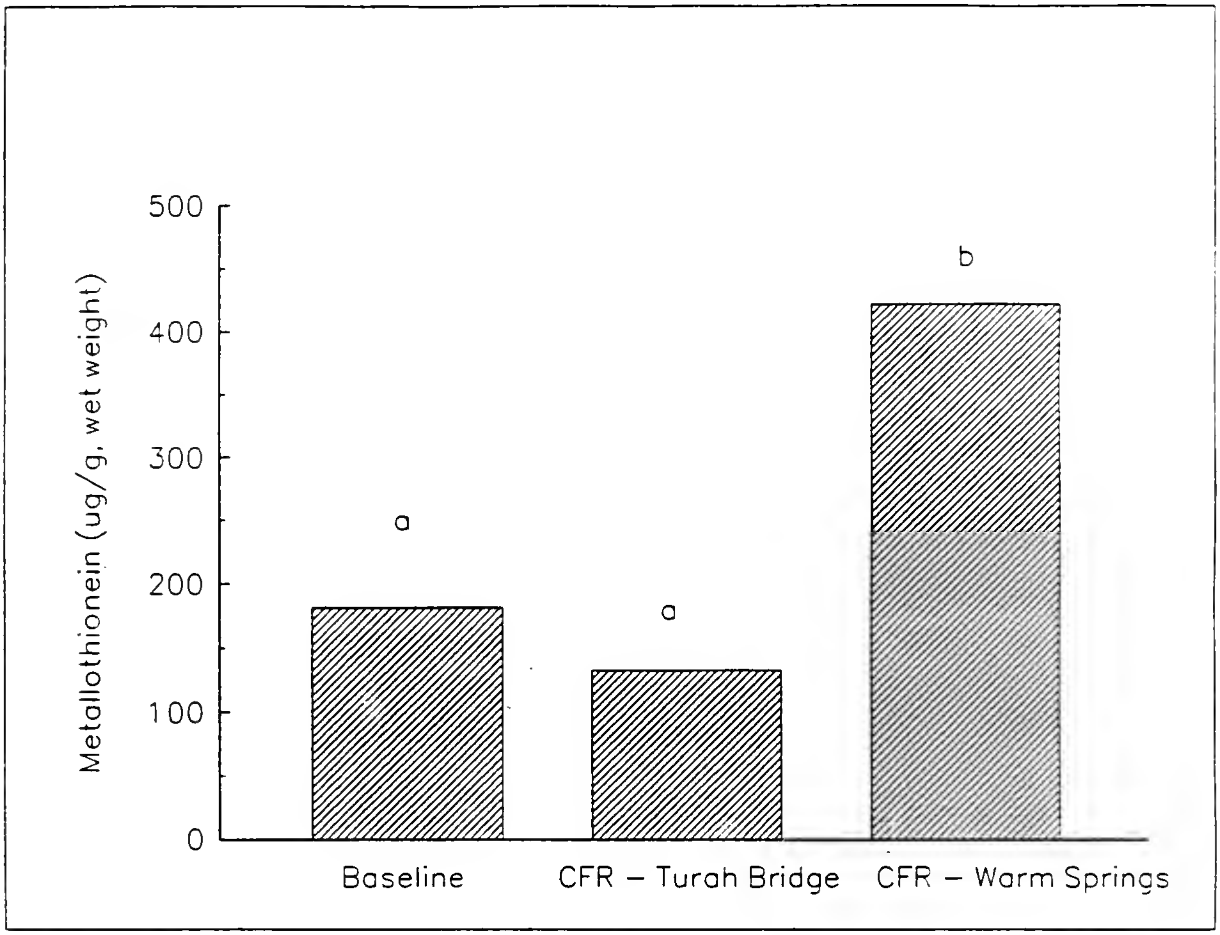

Figure 6-23. Metallothionein in brown trout collected form the Clark Fork River (Warm Springs and Turah Bridge sites) versus baseline. Baseline conditions determined from pooled data from two control sites: Big Hole River and Rock Creek. (* indicates significantly different from baseline, $p < 0.05$).

- Damage to liver cells in fish was observed in histopathological examination of fish collected from the field. The number and extent of damaged cells appeared to correspond to the degree of contamination of the site (Clark Fork River/Warm Springs > Clark Fork River/Turah Bridge > Rock Creek). No abnormalities were observed in livers from Big Hole River Fish.

- Increased lipid peroxidation was found in organs of fish collected from the Clark Fork River/Warm Springs site. Lipid peroxidation affects the integrity of cell membranes; these changes may ultimately result in tissue damage and cell death (Halliwell and Gutteridge, 1985, as cited in Appendix F).

- Increased concentrations of metallothionein were measured in livers of fish collected from the Clark Fork River/Warm Springs site. As described previously, metallothionein induction involves a physiological "cost of acclimation" that has been associated with reduced growth.

- Scale loss was observed in both laboratory experiments (in which adult trout were fed contaminated Clark Fork River invertebrates) and in free-ranging fish collected from the Clark Fork River. Scale loss can decrease resistance to disease and parasitism, and reduce survivability in the field.

- A reduction, although not statistically significant at the 5% level, was found in the growth condition factor of fish collected from the Clark Fork River/Warm Springs site relative to baseline. However, the measured condition factors appeared to vary with increasing contamination, with Clark Fork River/Warm Springs < Clark Fork River/Turah Bridge < Big Hole River < Rock Creek. Similarly, Tohtz (1992, as cited in Appendix F) found that 4,5, and 6 age-class brown trout from below Warm Springs were significantly smaller ($p<0.05$) than fish from the Big Hole River; the growth reductions observed in 1981 and 1989 were not statistically significant at the 5% level. Although these measured growth reductions were not found consistently to be statistically significant, they are consistent with the observed pattern of growth reductions observed in the laboratory feeding experiments described in Section 6.4.6 and by other researchers.

- The data collected from laboratory and field studies suggest strongly that reduced growth has resulted from exposure to hazardous substances. These data include: growth reductions in the laboratory feeding studies, observed digestive system degeneration in the feeding studies (including gut impaction and intestinal/pancreatic cell degeneration), increased lipid peroxidation in both laboratory and field studies, increased metallothionein in field studies, copper residues in both laboratory and field-collected trout at concentrations shown to cause growth reductions, reduced growth condition factors (not

statistically significant) in field-collected trout, and size reductions in field-collected fish. Although each of these results, individually, may not confirm growth reductions, the overall weight of evidence — and the consistent pattern that arises from the data — suggest that trout growth has been impaired.

Overall, the results of the fish health studies, including both laboratory and field assessments, present a consistent pattern of (1) exposure to hazardous substances, (2) cell damage (including digestive system degeneration, lipid peroxidation, and liver abnormalities), (3) scale loss, and (4) reduced growth. These health impairments likely contribute to reduced survivability of trout in the Clark Fork River.

6.4.8 Injury Determination Summary

The results of injury determination for fishery resources include the following conclusions:

- Injuries to fish that have resulted from exposure to hazardous substances in surface water and in food-chains include death, behavioral avoidance, reduced growth, and health impairment.

- Death has been confirmed in fishkills, *in situ* bioassays, and controlled laboratory studies.

- Laboratory studies demonstrated that exposure to acute pulses of elevated hazardous substances similar to those documented in the Clark Fork River causes significant trout mortality.

- Laboratory toxicity studies demonstrated that rainbow trout are more sensitive than brown trout to acute metals pulses in which pH and hardness decrease.

- Standard laboratory toxicity studies (LC50, LT50 determinations) demonstrated that exposure to copper, cadmium, lead, and zinc at concentrations documented in the Clark Fork River causes significant trout mortality.

- Laboratory studies demonstrated that both brown and rainbow trout avoid hazardous substances at concentrations regularly documented in the Clark Fork River. These studies also determined that rainbow trout are more sensitive than brown trout in avoiding hazardous substances.

- Behavioral avoidance likely limits the immigration of fish ("recruits") from tributaries into the mainstream Clark Fork River, as well as causing emigration to tributaries.

- Laboratory studies documented that food-chain pathways injure trout. Fish fed diets of contaminated Clark Fork River invertebrates demonstrated increased mortality, decreased growth, and health impairment.

- Reduced growth, an indicator of compromised survivability in the field, was documented in controlled laboratory studies. The weight of evidence suggests that growth has been reduced in free-ranging fish collected from the Clark Fork River.

- A consistent pattern of metal accumulation in tissues, degeneration of digestive cells (likely leading to reduced growth), cellular damage, and synthesis of metal-binding proteins required to detoxify/excrete metals (production of which entails a metabolic cost which has been shown to reduce growth and long-term survivability) was observed in both laboratory-exposed and free-ranging organisms from the Clark Fork River.

The above conclusions all indicate the presence of multiple and pervasive injuries to resident fish of the Clark Fork River.

6.5 INJURY QUANTIFICATION

The preceding sections have demonstrated that fish have been injured throughout Silver Bow Creek and the Clark Fork River. This section quantifies those injuries to the fisheries resource in terms of reductions in trout populations in Silver Bow Creek and the Clark Fork River relative to baseline conditions.

This section contains three sections. Section 6.5.1 describes the process of injury quantification as outlined in 43 CFR § 11.71. Section 6.5.2 briefly describes the methodologies used to quantify fish injury in this report. In Section 6.5.3, injuries to the fisheries resource in Silver Bow Creek and the Clark Fork River are quantified.

6.5.1 Injury Quantification

43 CFR § 11.71 (l) presents guidelines for quantifying injury to biological resources such as fisheries. These guidelines suggest the following:

- The extent to which the injured biological resource differs from baseline should be determined by analysis of the population...levels [43 CFR § 11.71 (l)(1)].

- Population changes...should be based upon species...that represent broad components of the ecosystem..., that are especially sensitive to the hazardous substance..., [or] that provide especially significant services [43 CFR § 11.71 (l)(2)(i-iii)].

- Population measurement methods should... provide numerical data that will allow comparison between assessment area data and control area or baseline data..., provide data that will be useful in planning restoration or replacement efforts..., and allow correction, as applicable, for factors such as dispersal of organisms in or out of the assessment area...and other potential systematic biases in the data collection [43 CFR § 11.71 (l)(4)(i-iii)].

- When estimating population differences in animals, ...estimation techniques appropriate to the species and habitat shall be used [43 CFR § 11.71 (l)(5)].

The injury to fisheries in the upper Clark Fork River Basin has been quantified in accordance with these regulations.

6.5.2 Methodologies for Quantifying Fisheries Injury

A detailed account of fisheries injury quantification methodologies is provided in Appendix G.[15] In general, the approach used was based on the following steps:

- Select control sites for Silver Bow Creek and the Clark Fork River using objective criteria.

- Measure fish population density and available habitat at control sites to quantify baseline conditions in terms of trout abundance and biomass.

- Measure available habitat and trout abundance and biomass at sites in Silver Bow Creek and the Clark Fork River to determine injured population sizes (number of fish per unit habitat).

- Quantify injury in terms of significant differences from baseline.

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[15] "Assessment of injury to fish populations: Clark Fork River NPL sites, Montana," by Don Chapman Consultants, Inc.

A brief overview of these methods is presented below.

6.5.2.1 Control Site Selection

The Clark Fork River and Silver Bow Creek were divided into reaches with similar ecologic, geologic, geomorphic, hydrologic, and riparian ("state type") characteristics. Using maps, aerial photographs, and field observations, matching control stream reaches were selected having the same characteristics as the Clark Fork reaches (see Appendix G and Table 6-16). Thus, test and control sites were matched to control for geology, land type, valley bottom type, and land and water uses.

Trout abundance was measured at four reaches in Silver Bow Creek; these reaches were matched to four control reaches — two in Bison Creek, and one each in the Ruby River and the Big Hole River (Table 6-17, Figure 6-24). Fish population density and biomass was measured at 14 Clark Fork River reaches between Warm Springs Ponds and the Milltown Reservoir and 14 corresponding reference sites (Figure 6-24 and Table 6-18).

6.5.2.2 Habitat and Fish Population Measurements

Once test and control reaches were matched, four 100-meter sections (defined as "sites" in Appendix G) of each selected river reach were randomly selected for measurement of trout density and biomass. One of the four 100-meter sections then was randomly selected for measurement of microhabitat variables[16] and for Physical Habitat Simulation (PHABSIM) modeling. The physical habitat modeling enabled the comparisons of trout densities and biomass between test and control sites to be normalized for habitat or flow differences. The normalized habitat data from PHABSIM provided units of weighted usable area (WUA) of fish habitat in each river reach. Fish densities were thus expressed as the number or biomass of fish per WUA at summer flows, and as numbers or biomass of fish per unit surface area (hectares).

Trout populations were counted in each designated stream section using either direct underwater observation (snorkeling) or electrofishing. Underwater observation by snorkeling has been shown to be an unbiased census technique when stream temperature is above 14°C and concealment cover is not obstructive (Schill and Griffith, 1984; Hillman *et al.*, 1992). All trout greater than 1" in length were counted in each 100-meter stream segment. Electrofishing was used in rivers where poor water clarity precluded the use of snorkeling, as well as for validating the snorkel estimates of fish populations.

[16] Microhabitat variables measured were: channel width, wetted perimeter width, riffle width, run width, pool width, pool rating, bank angle, average and thalweg depth, substrate, bank cover, vegetative overhang, canopy cover, bank alteration, woody debris, sun arc, and bank undercut (Appendix G).

Table 6-16
Hierarchical Classification of Valleys and Rivers Used to Match Appropriate Reference Sites to Segments of the Clark Fork River and Silver Bow Creek

Hierarchical Level	Description
Ecoregion	An area determined by similar land-surface form, potential natural vegetation, land-use and soil.
Geologic district	A portion of an ecoregion with relatively homogeneous parent materials, distinguished from surrounding districts by structure, degree of weathering, dominant size-fractions of weathering products and water-handling characteristics; includes both uplands and bottomlands.
Landtype association	A part of a geologic district that is distinguished by a dominant geomorphic mechanism (e.g., glacial, fluvial, alluvial, lacustrine); includes both uplands and bottomlands.
Landtype	A portion of a landtype association distinguished by form and position, corresponding with associations of soils and plant communities.
Valley-bottom type	A subset of the valley-bottom landtype distinguished by form, structure, and the manner in which water and sediments move through the system; they are generally distributed in a predictable manner along the elevational gradient of watersheds.
State type	A part of the valley-bottom type distinguished by the condition of the stream and its banks (e.g., eroded banks, laid-back banks, channelized, braided).

Source: Appendix G.

Table 6-17
Rivers Used as Control Sites for the Four Silver Bow Creek Fish Population Sampling Areas

Test Site	Reference (Control) Site
Silver Bow Creek Sample Site 1	Ruby River Sample Site 2
Silver Bow Creek Sample Site 2	Big Hole River Sample Site 1
Silver Bow Creek Sample Site 3	Bison Creek Sample Site 1
Silver Bow Creek Sample Site 4	Bison Creek Sample Site 2

Note: Sample site numbers are from downstream to upstream. Approximate sampling locations may be found in Figure 6-22.

Source: Appendix G.

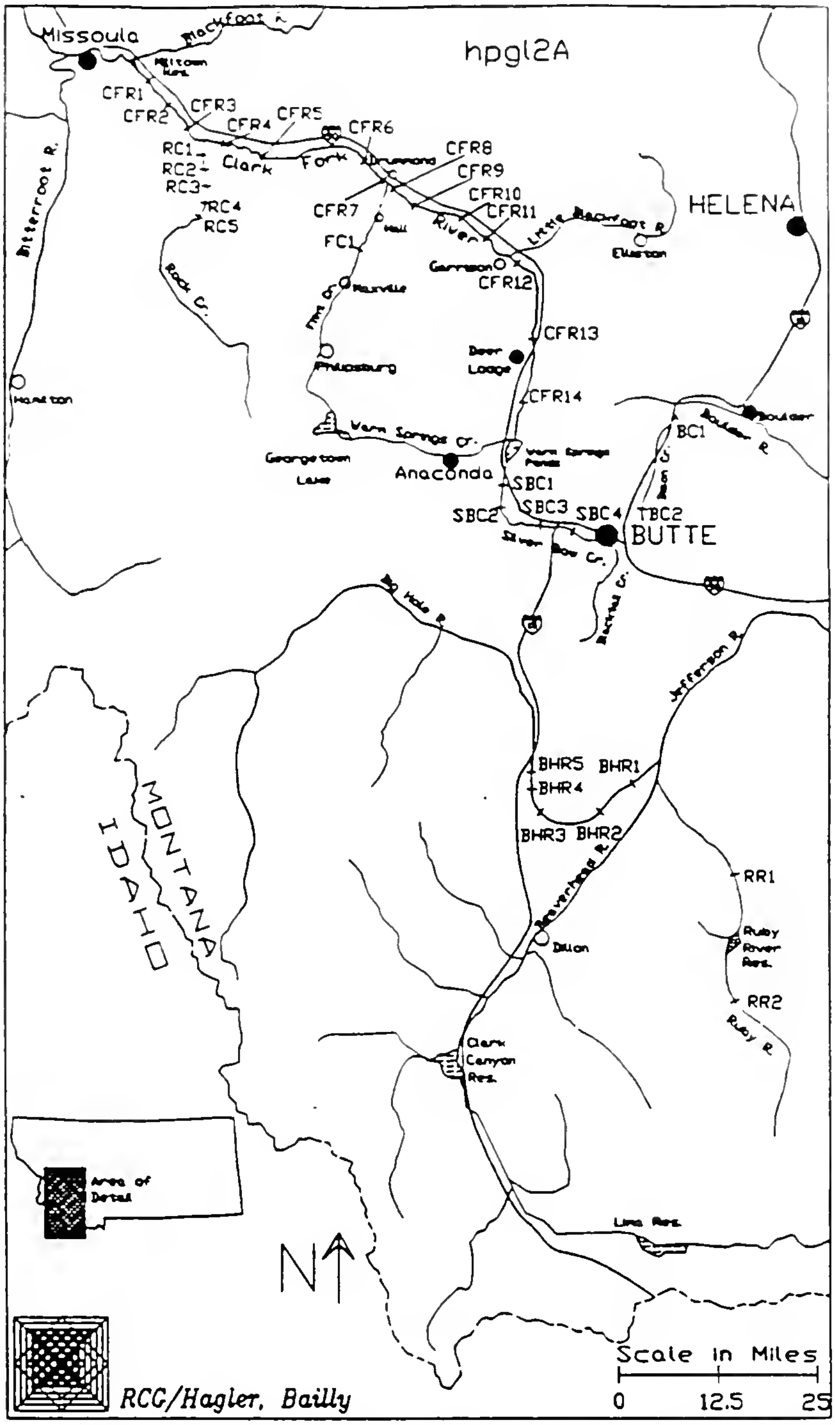

Figure 6-24. **Approximate Fish Population Sampling Locations for Test and Reference Streams.** CFR = Clark Fork River; SBC = Silver Bow Creek; RC = Rock Creek; FC = Flint Creek; BC = Bison Creek; BHR = Big Hole River; RR = Ruby River.

Table 6-18
Rivers Used as Control Sites for the
14 Clark Fork River Fish Population Sampling Areas

Test Site	Control Site
Clark Fork River Sample Site 1	Rock Creek Sample Site 3a
Clark Fork River Sample Site 2	Rock Creek Sample Site 3b
Clark Fork River Sample Site 3	Rock Creek Sample Site 3a-b
Clark Fork River Sample Site 4	Rock Creek Sample Site 1
Clark Fork River Sample Site 5	Rock Creek Sample Site 4
Clark Fork River Sample Site 6	Rock Creek Sample Site 2
Clark Fork River Sample Site 7	Big Hole River Sample Site 5a
Clark Fork River Sample Site 8	Big Hole River Sample Site 4
Clark Fork River Sample Site 9	Big Hole River Sample Site 3
Clark Fork River Sample Site 10	Big Hole River Sample Site 5b
Clark Fork River Sample Site 11	Big Hole River Sample Site 2
Clark Fork River Sample Site 12	Flint Creek Sample Site 1a
Clark Fork River Sample Site 13	Ruby River Sample Site 1
Clark Fork River Sample Site 14	Flint Creek Sample Site 1b

Note: Sample site numbers are from downstream to upstream. Approximate sample locations may be found in Figure 6-23.

Source: Appendix G.

6.5.3 Fisheries Injury

Trout were significantly more abundant ($p<0.001$) in control reaches than in impacted reaches in the Clark Fork River (Figure 6-25).

In Silver Bow Creek, no fish were observed at any of the four test reaches on the creek; these results agree with previous investigations documenting the complete absence of all fish in Silver Bow Creek. By contrast, trout densities at matching controls ranged from a low of 34 trout per hectare to a high of 558 trout per hectare (average of the four control reaches equal to 261 trout per hectare). Brown, rainbow, and brook trout were all observed at Silver Bow Creek control reaches. Some control sites were severely altered by grazing; these severely grazed areas were selected to match Silver Bow Creek reaches severely altered by hazardous substances contained in streamside tailings deposits. The control sites thus represent a conservative baseline because the trout

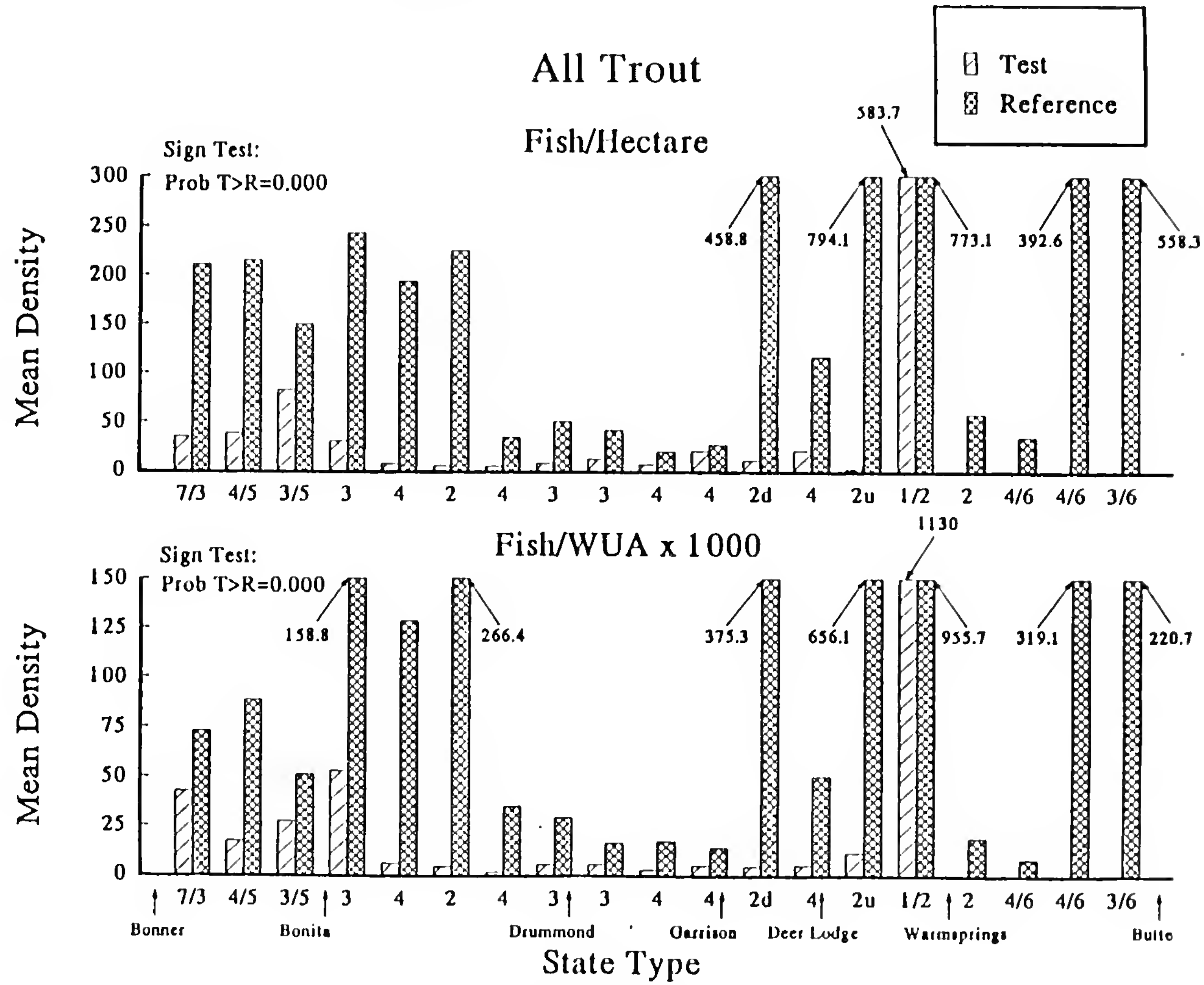

Figure 6-25. **Mean Densities of All Trout in Test Reference States.** Upper figure shows number of trout per hectare; lower figure show number of fish normalized for habitat (weighted usable area, or WUA). Source: Appendix G.

densities at the grazed reached were lower than they would have been in un-grazed stream areas.

In the Clark Fork River, trout density ranged from a low of 2 fish/hectare (approximately 5 miles downstream of the Warm Springs Ponds) to a high of 583 fish/hectare (immediately downstream of the Warm Springs Ponds) (Table 6-19). At the matching control reaches, trout density ranged from a low of 19 fish/hectare to a high of 794 fish/hectare. The ratio of trout density in the Clark Fork River reaches to the matching control reaches ranged from roughly 1:1.3 to 1:400. Overall, trout were more than 4 times more abundant in control reaches than in the Clark Fork River. Similarly, total trout biomass was more than 4 times greater at control reaches than in the Clark Fork River (Figure 6-25, Table 6-19). When normalized for habitat and flow effects (WUA) and weighting the data by the relative length of the reaches. average baseline trout abundance was more than three times larger than in the Clark Fork River.[17] Juvenile trout (2-8 inches) made up 66% of all trout at Clark Fork River sites and 63% of the trout at control sites. Again, average juvenile trout abundance and biomass were approximately 4 times greater at control sites than in the Clark Fork River, and approximately two times greater when normalized for habitat (unweighted value). A similar pattern was observed for adult trout.

Brown trout were significantly more abundant at control sites than in the Clark Fork River ($p<0.001$) (Figure 6-26). Average brown trout abundance and biomass, respectively, were roughly 4 and 5 times greater at control sites (approximately two times greater when normalized for habitat; not weighted by reach length). Similarly, rainbow trout were significantly more abundant at control sites than in the Clark Fork River ($p<0.001$) (Figure 6-27). In the Clark Fork River, rainbow trout were principally observed downstream of Rock Creek — as has been reported by numerous investigators. Average rainbow trout abundance in control sites was over five times that of the Clark Fork River, even when normalized for habitat. This absence of rainbow trout is consistent with their observed sensitivity to pulse toxicity and behavioral avoidance.

Summary and Conclusions

Trout populations and biomass in Silver Bow Creek and the Clark Fork River were found to be significantly less than at control sites. The methodology that was used accounted for differences in habitat and flow — hence, the observed population reductions in Silver Bow Creek and the Clark Fork River were not caused by either of

[17] Again, these differences between Clark Fork River and baseline conditions are based on weighting the population data by the relative lengths of the reaches in the Clark Fork River. Appendix G reports average differences between Clark Fork River and control reaches without weighting the data for reach size. These unweighted average differences are slightly less than the weighted differences.

Table 6-19
Trout Density and Biomass: the Clark Fork River, Silver Bow Creek, and Matching Control Streams

		Number/Ha		(Number/WUA)*1000		Weight/Ha		(Weight/WUA)*1000	
Reach	State code	Test	Reference	Test	Reference	Test	Reference	Test	Reference
1	7/3	34.5	210.9	42.4	72.8	8.8	41.6	6.6	11.2
1	4/5	38.0	214.8	17.0	88.2	14.0	46.6	5.5	13.3
1	3/5	81.9	148.1	27.0	50.7	27.5	28.1	6.5	7.4
2	3	29.9	241.8	52.5	158.8	6.3	53.3	6.8	21.6
2	4	6.5	193.1	5.5	128.2	3.9	52.2	3.2	21.8
2	2	4.5	224.1	4.0	266.4	1.0	41.2	1.0	32.5
3	4	4.3	33.9	1.2	34.7	1.3	9.0	0.4	9.0
3	3	7.0	50.3	5.1	28.7	2.8	25.3	2.2	14.9
4	3	11.6	41.2	5.0	15.8	4.2	18.5	1.8	6.6
4	4	5.8	19.2	2.3	16.7	2.7	4.2	1.2	3.0
5	4	19.8	26.4	4.7	13.5	8.7	6.9	2.2	3.5
6	2d	10.1	458.8	4.1	375.3	4.1	126.1	1.7	105.4
6	4	20.6	116.3	4.6	49.7	4.1	22.3	0.9	9.6
6	2u	2.1	794.1	10.9	656.1	0.3	271.2	1.4	226.3
6	1/2	583.7	773.7	1130.0	955.7	126.9	234.4	333.4	300.8
7	2	0.0	57.4	0.0	18.4	0.0	12.9	0.0	4.0
7	4/6	0.0	34.2	0.0	7.8	0.0	8.2	0.0	2.7
9	4/6	0.0	392.6	0.0	319.1	0.0	69.7	0.0	45.4
10	3/6	0.0	558.3	0.0	220.7	0.0	26.8	0.0	11.0

Source: Appendix G.

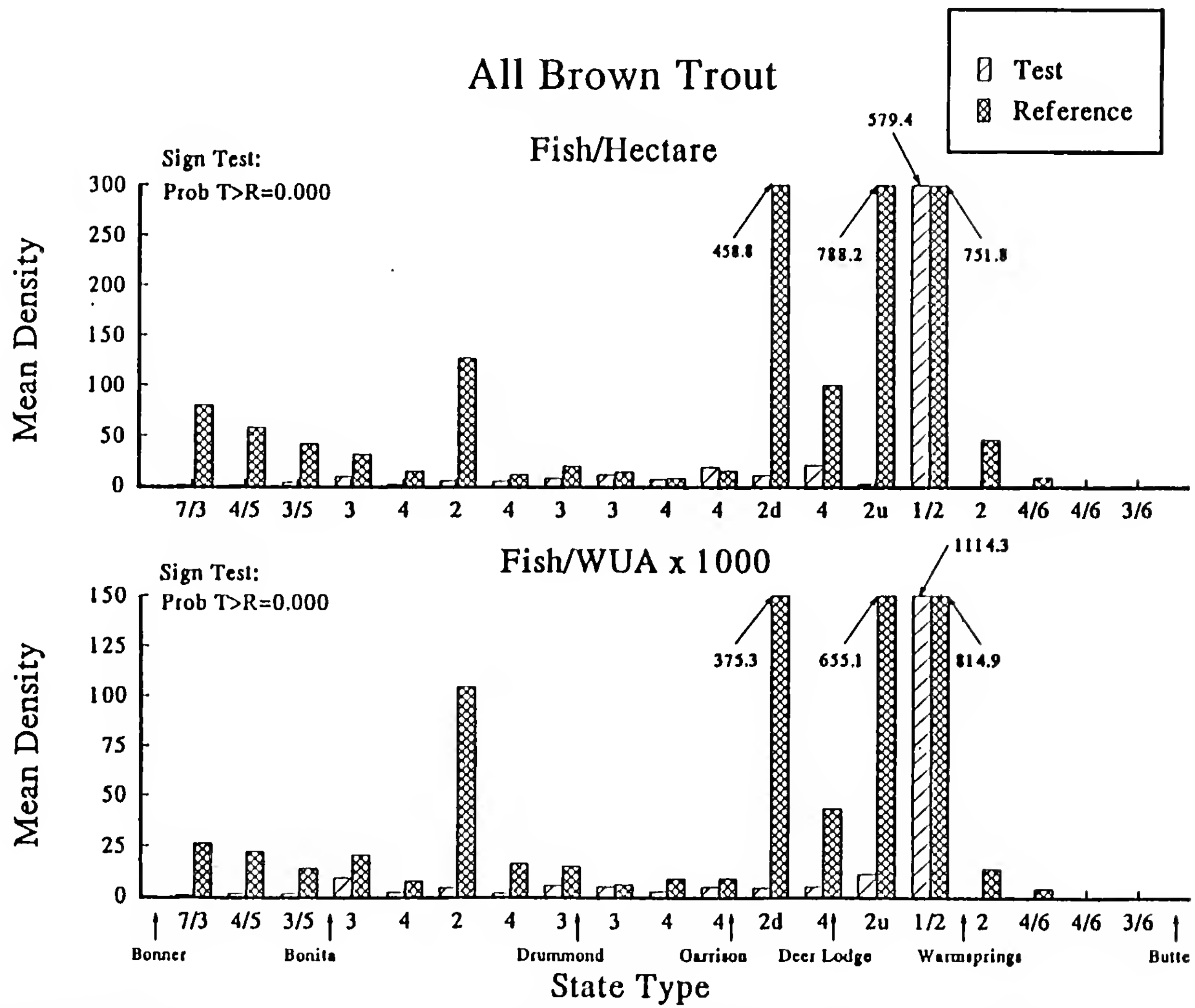

Figure 6-26. **Mean Densities of all Brown Trout in Test and Reference States.** Source: Appendix G.

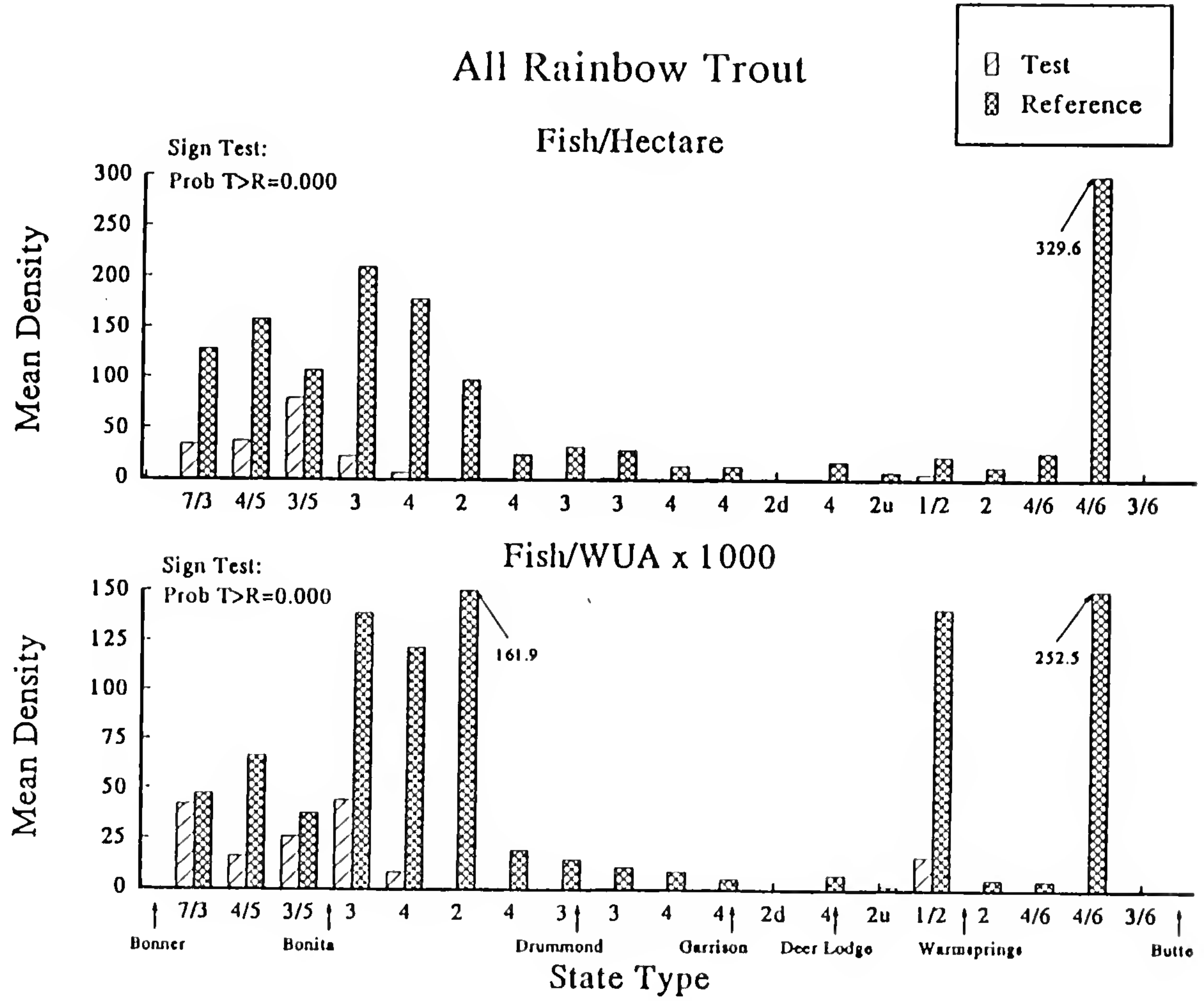

Figure 6-27. Mean Densities of All Rainbow Trout in Test and Reference States. Source: Appendix G.

these variables. Trout were more abundant at all control reaches than at matching Silver Bow Creek and Clark Fork River reaches, with an overall difference in trout abundance between the Clark Fork River and baseline being more than three-fold.

6.5.4 Injury Quantification Summary

The results of injury quantification for fishery resources of Silver Bow Creek and the Clark Fork River include the following conclusions:

- No fish exist in Silver Bow Creek despite the availability of habitat. By contrast, Silver Bow Creek baseline conditions supported, on average, over 250 trout per hectare, including rainbow trout, brown trout, and brook trout. Moreover, this baseline estimate is conservative because control sites were severely altered by grazing to match the habitat degradation in Silver Bow Creek caused by streamside tailings.

- Overall, trout density in the Clark Fork River is less than one-fourth of baseline. When normalized for habitat and river length, trout density in the Clark Fork River is less than one-third of baseline.

- Both brown trout and rainbow trout were significantly more abundant at control sites. Brown trout numbers and biomass in Clark Fork River sites were both roughly one-fourth of baseline. Rainbow trout numbers and biomass were roughly one-fifth of baseline (including when the data were normalized for habitat).

- Rainbow trout largely are absent from the Clark Fork River upstream of its confluence with Rock Creek. This observation is consistent with the sensitivity of rainbow trout to acute pulse toxicity and to behavioral avoidance, as shown in injury determination sections.

Overall, the conclusion to be drawn from the injury quantification phase is that the injuries that have resulted from exposures to hazardous substances have resulted in the total elimination of fish from Silver Bow Creek, substantial reductions in the number of trout present in the Clark Fork River, and reductions in the diversity of trout species in Silver Bow Creek and the Clark Fork River.

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